QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE PERMANENT SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant —Novum Organum, Præfatio.

VOLUME THE EIGHTY-FIRST,

FOR 1925.

LONDON:

LONGMANS, GREEN, AND CO.
PARIS: CHARLES KLINCKSIECK, 11 RUE DE LILLE.
SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.
MOMXXV.

OFFICERS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

Elected February 20th, 1925.

Bresident.

John William Evans, C.B.E., D.Sc., LL.B., F.R.S.

Wice-Bresidents.

Sir John Smith Flett, K.B.E., M.A., LL.D., | Prof. Albert Charles Seward, Sc.D., D.Sc., M.B., F.R.S. Sir Thomas Henry Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S.

F.R.S., F.L.S. Sir Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

Decretaries.

Walter Campbell Smith, M.C., M.A.

James Archibald Douglas, M.A., D.Sc. Treasurer.

Foreign Secretary.

Prof. John Edward Marr, M.A., Sc.D., | Robert Stansfield Herries, M.A.

COUNCIL. Prof. Percy George Hamnall Boswell,

O.B.E., D.Sc. Prof. Arthur Hubert Cox, D.Sc., Ph.D.

Thomas Crook. Henry Dewey.

James Archibald Douglas, M.A., D.Sc.

Gertrude Lilian Elles, M.B.E., D.Sc. John William Evans, C.B.E., D.Sc., LL.B., Prof. William George Fearnsides, M.A.

Sir John Smith Flett, K.B.E., M.A., LL.D., D.Sc., M.B., F.R.S. Prof. William Thomas Gordon, M.A.,

D.Sc., F.R.S.E. Prof. Herbert Leader Hawkins, D.Sc.

Robert Stansfield Herries, M.A.

Sir Thomas Henry Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S.

William Dickson Lang, M.A., Sc.D. Prof. John Edward Marr, M.A., Sc.D.,

Horace Woollaston Monckton, Treas.L.S. Tressilian Charles Nicholas, O.B.E., M.C., M.A.

Prof. Albert Charles Seward, Sc.D., F.R.S., F.L.S.

Walter Campbell Smith, M.C., M.A. Leonard James Spencer, M.A., Sc.D.

Arthur Elijah Trueman, D.Sc. Henry Woods, M.A., F.R.S.

Sir Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

Bermanent Becretary.

L. L. Belinfante, M.Sc.

Librarian

Arthur Greig.

STANDING PUBLICATION COMMITTEE.

Dr. J. W. Evans, President.

Mr. W. Campbell Smith. } Secretaries. Mr. R. S. Herries, Treasurer. Dr. J. A. Douglas.

Dr. F. A. Bather. Prof. P. G. H. Boswell. Prof. W. G. Fearnsides. Sir John S. Flett. Prof. H. L. Hawkins.

Dr. W. D. Lang. Prof. J. E. Marr. Mr. T. C. Nicholas. Dr. L. J. Spencer. Sir Aubrey Strahan.

Prof. W. W. Watts. Mr. H. Woods. Sir A thur Smith Woodward.

TABLE OF CONTENTS.

Page
Andrew, Gerald. The Llandovery Rocks of Garth, Breconshire (Plate XXII)
—— (& Jones, O. T.). The Relations between the Llandovery Rocks of Llandovery and those of Garth
BALDRY, ROBERT ASHLEY. See below.
Brown, Charles Barrington (& Baldry, R. A.). On the Clay Pebble-Bed of Ancon, Ecuador (Plates XXVIII & XXIX) 455
Cox, Arthur Hubert. The Geology of the Cader Idris Range, Merioneth (Plates XXXIII-XXXVII)
CROSFIELD, MARGARET CHORLEY. See Woods.
DIXEY, FRANK. The Geology of Sierra Leone (Plates XII-XIV). 195
GUPPY, EILEEN MARY (& HAWKES, L.). A Composite Dyke from Eastern Iceland (Plates XIX & XX)
HAWKES, LEONARD. See above.
HILTON, H. On the Cooling of a Dyke
Hooley, Reginald Walter. On the Skeleton of Iguanodon atherfieldensis sp. nov. from the Wealden Shales of Atherfield, Isle of Wight (Plates I & II)
JONES, OWEN THOMAS. The Geology of the Llandovery District: Part I—The Southern Area (Plate XXI)
See also Andrew, G.
Kennard, Alfred Santer (& Woodward, B. B.). The Pleistocene Non-Marine Mollusca of the Avon Valley 164
MARR, JOHN EDWARD. Conditions of Deposition of the Stockdale Shales of the Lake District
NUTTALL, WINFRED LAURENCE FALKINER. The Stratigraphy of the Laki Series (Lower Eccene) of parts of Sind and Baluchi- stan (India); with a Description of the Larger Foraminifera contained in those Beds (Plates XXIII-XXVII)

RASTALL, ROBERT HERON. Petrographical Notes on the Stock-dale Shales
RAW, Frank. The Development of Leptoplastus salteri (Callaway) and of other Trilobites [Olenidæ, Ptychoparidæ, Conocoryphidæ, Paradoxidæ, Phacopidæ, and Mesonacidæ] (Plates XV-XVIII)
Sandford, Kenneth Stuart. The Fossil Elephants of the Upper Thames Basin (Plates III-VI)
Spencer, Edmondson. On some Occurrences of Spherulitic Siderite and other Carbonates in Sediments (Plates XLII & XLIII)
SWINNERTON, HENRY HURD. A New Catopterid Fish from the Keuper of Nottingham (Plates VII & VIII)
TILLEY, CECIL EDGAR. A Preliminary Survey of Metamorphic Zones in the Southern Highlands of Scotland (Plate IX) 100
Tomlinson, Mabel Elizabeth. River-Terraces of the Lower Valley of the Warwickshire Avon (Plate X)
TUTCHER, JOHN WILLIAM (& TRUEMAN, A. E.). The Liassic Rocks of the Radstock District, Somerset (Plates XXXVIII– XLI)
TRUEMAN, ARTHUR ELIJAH. See above.
Wells, Alfred Kingsley. The Geology of the Rhobell Fawr District, Merioneth (Plates XXX-XXXII)
Woods, Ethel Gertrude (& M. C. Crosfield). The Silurian Rocks of the Central Part of the Clwydian Range (Plate XI) . 170
Woodward, Bernard Barham. See Kennard.
Commence
PROCEEDINGS.
Proceedings of the Meetings i, cxxiv
Special General Meeting ii
Annual Report ix
Lists of Donors to the Library xiv
List of Donors to the Voluntary Publication Fund xx
List of Foreign Members xxvi
List of Foreign Correspondents xxvii
List of Wollaston Medallists xxviii
List of Murchison Medallists, xxix
List of Lyell Medallists

SCHAFFER, FRANZ XAVER. On the History of the Vienna

Basin

i

LIST OF THE FOSSILS FIGURED AND DESCRIBED IN THIS VOLUME.

Name of Species.	Formation.	Locality.	- V 10				
FORAMINIFERA.							
Alveolina lepidula, pl. xxiv, figs. 1 & 2 — oblonga, pl. xxiv, figs. 7 & 8 — ovicula sp. nov., pl. xxiv, figs. 9 & 10 — subpyrenaica, pl. xxiii, figs. 1-3 & pl. xxiv, fig. 3. Assilina granulosa, pl. xxiii, figs. 1-5 — leymeriei, pl. xxv, fig. 8 Ploscocyclina archiaci var. baluchistanensis nov., fig. 5 & pl. xxvii, figs. 8 Flosculina globosa, pl. xxiii figs. 1, 4, & pl. xxiv, figs. 4-6 Nummulites atacicus, pl. xxv, figs. 1-6 — irregularis, pl. xxvii, figs. 1-3 — mamilla, pl. xxvii, figs. 1-3 — subatacicus, pl. xxv, fig. 7 Opertorbitolites douvillei gen. et sp. nov., pl. xxvii, figs. 4-7	Laki Series	Sind & Balu- chistan	439-40 440-41 439 434 441-43 444-45 446-47 435-39 444-45 446 445-46 445-46 447-48				
	TRILOBITA.						
Leptoplastus salteri, text-fig. (p. 249) & pls. xv-xviii		Various	223-57				
LAMELLIBRANCHIATA.							
Gryphæa aff. dumortieri, fig. 17 a — incurva var. crassi- rugata nov, fig. 17 c — aff. obliqua, fig. 17 b	Angulata Zone. Spiriferina - walcotti Bed. Armatum Bed.	$\left. egin{array}{c} Welton & \dots & \\ Kilmersdon & \\ Road & \dots & \end{array} \right.$	$ \begin{cases} 652, 653 \\ 652-53 \\ 653 \end{cases} $				

Name of Species.	Formation.	Locality.	Page
	Ammonoidea.		
Acanthopleuroceras lepidum sp. nov., pl. xl, figs. 1 a & 1 b	Valdani Lime- stone	Radstock	651-52
fig. 12 d & pl. xxxix, figs. 1 a-1 b	Obtusum Bed Agassiceras Bed.	Timsbury	637-38
& pl. xxxviii, figs. 1 a-1 c notatum sp. nov., fig. 12 b & pl. xxxix, figs. 2 a-2 b	Bucklandi Bed.	Rockhill	638-39
Gleviceras aff. glevense, fig. 13 Oxynoticeras williamsi sp. nov., pl. xli, figs. 3 a-3 c	Armatum Bed.	$\begin{cases} \text{Kilmersdon} \\ \text{Road} \\ \text{Rockhill} \dots \end{cases}$	642 644
Pararnioceras sp., fig. 12 a & pl. xxxviii, figs. 2a-2c	Lower Lias	Radstock district	${637, 640-41}$
Peripleuroceras rotundicosta gen. et sp. nov., pl. xli, figs. 1 a-1 c	Jamesoni Limestone,	Kilmersdon Road	646
latum sp. nov., fig. 16 e & pl. xxxix, figs. 3 a-3 b	Jamesoni Limestone	Various	650-51 }649
	Jamesoni Limestone Lower Li	Clandown	$ \begin{array}{c} 650 \\ 650 \\ 648 \end{array} $
Uptonia aff. & cf. angusta, figs. 15 b & 15 c	Jamesoni Limestone	district. Timsbury	647 647-48 } 646-47
— jamesoni, fig. 15 a Victoriceras iridescens sp. nov., fig. 14	Armatum Bed	Westfield	643
	CATOPTERIDÆ.		
Woodthorpea wilsoni gen. et sp. nov., figs. 1-3 & pls. vii-viii	Keuper	\ \begin{cases} \text{Woodthorpe,} & \ & \text{near} & \ & \text{Nottingham.} \end{cases}	87-99
	DEINOSAURIA.		
Iguanodon atherfieldensis sp. nov., figs. 1-10 & pls. i-ii.	Wealden Shales	Atherfield	1-60
	PROBOSCIDEA.		
Elephas antiquus, pl. iii, figs. 1 & 2, pls. iv & v, pl. vi, fig. 5 — primigenius, pl. vi, figs. 1-4 & 6-7 — trogontherii, pl. iii, fig. 3	Pleistocene	Upper Thames Basin	69, 70-7 77, 80-8

EXPLANATION OF THE PLATES.

Plates		PAGE
I & II RIGHT RAMUS OF MANDIBLE, ETC., OF IGUANODON ATHE	$\left\{ \begin{array}{c} R^{-} \\ N \end{array} \right\}$	1
III-IV Molars and Mandible of Elephas antique E. trogontherit, and E. primicentus, illustrati Dr. K. S. Sandford's paper on the Fossil Elephan of the Upper Thames Basin		62
VII & VIII HEAD, TAIL, AND DORSAL FIN OF WOODTHORP WILSONI gen. et sp. nov., illustrating Prof. H. Swinnerton's paper on that fossil	$\left\{ egin{array}{l} EA \\ H. \\ \ldots \end{array} \right\}$	87
PLATE IX MAP OF THE SOUTHERN HIGHLANDS OF SCOTLAN illustrating Dr. C. E. Tilley's paper on the Me morphic Zones of that region	ta-	100
X MAP ILLUSTRATING THE PLEISTOCENE DEPOSITS OF T LOWER VALLEY OF THE WARWICKSHIRE AVON, A SECTION SHOWING THE GRADIENTS OF THE LOW AVON RIVER-TERRACES, illustrating Miss M. E. To linson's paper on those terraces	HE and	137
XI Geological Sketch-map of the Central Part of t Clwydian Range, illustrating the paper by M E. G. Woods & Miss M. C. Crosfield on t Silurian rocks of that area	rs.	170
PLATES		
XII-XIV THE SAIONIA SCARP AND GRANITE ON THE LAGE PANGUMA ROAD; THE SANDY PLAINS OF GAHNIA A HILL OF PLATEAU SANDS NEAR KUNDUKONKO; A GEOLOGICAL MAP OF SIERRA LEONE, illustrating F. Dixey's paper on the geology of the last-name region	nd nd Dr.	195
$\textbf{XV-XVIII} \left\{ \begin{array}{l} \textbf{OUTLINES OF DIFFERENT TYPES OF TRILOBITE CEPHA} \\ \text{and Photographs of } \textit{Leptoplastus salteri, ill} \\ \text{trating Mr. F. Raw's paper on the development} \\ \textit{L. salteri} \text{ and of other Trilobites} \\ \end{array} \right.$	us-	223
XIX & XX VIEW OF HÖKULVIKURFJÄLL AND VIEW OF THE ENTRAL TO HÖKULVIKURGIL; also MICROSCOPE-SECTIONS HÖKULVIKURGIL DYKE-ROCKS, illustrating the pa by Miss E. M. Guppy & Mr. L. Hawkes on a Co posite Dyke from Eastern Iceland	or per >	325

- Folding Table of the Denbighshire Series on the Clwydian Range, facing p. 180, and illustrating the paper by Mrs. E. G. Woods & Miss M. C. Crosfield on the Silurian rocks of that range.
- Folding Table of the Dimensions and Form-Ratios of twenty-three Individuals of Leptoplastus salteri, facing p. 242, and illustrating Mr. F. Raw's paper on the development of that form.
- FOLDING TABLE OF ZONAL TERMS IN THE LOWER LIAS, facing p. 598, and illustrating the paper by Mr. J. W. Tutcher and Dr. A. E. Trueman on the Liassic Rocks of the Radstock District.

PROCESS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES BESIDES THOSE IN THE PLATES.

PAGE		
2	Skull of Iguanodon atherfieldensis	Fig. 1.
6	Maxilla, nasal and lachrymal bones, etc. of the same	2.
10	Jugal, quadrate, squamosal, and pterygoid bones, etc. of the same	3.
14	Left mandible, coronoid process, etc. of the same	4.
2 2	Pro-atlas, atlas, dorsal, cervical, and caudal vertebræ of the same	5.
28	Various aspects of the sacrum of the same	6.
34	Left scapula and coracoid, left humerus, and sternal bones of the same	7.
36	Bones of the right fore-limb, various aspects of the left carpus, and metatarsals, etc. of the right hand of the same	8.
44	Right femur, right fibula and tibia, and left distal row of tarsals of the same	9.
46	Left pelvic girdle, dorsal and cervical ribs, and dorso- lumbar vertebræ of the same	10.
67	Diagram of elephant molar	
90	Woodthorpea wilsoni, specimens 3 & 4	Figs. 1 & 2.
91	Restoration of Woodthorpea wilsoni	Fig. 3.
121	Dwarf fossils from the blue muds of the Skelgill Beds	1.
123	Sketch-map, showing localities in Europe and the British Isles where the Stockdale Shales or their equivalents were deposited	2.
126	Diagram representing the conditions which prevailed during the deposition of dark graptolitic muds	3.
142	Section through No. 5 Terrace at Strensham	1.

Fig.	2.	Section through No. 4 Terrace at Cropthorne	146
	3.	Section through Bricklehampton Bank, Cropthorne	147
	4.	Diagram showing that the relative ages of river-gravels cannot always be deduced from a consideration of their height above the present thalweg	156
	5.	Diagram showing the magnitude and order of the stages in the development of the present valleys of the Avon, Somme, and Cam	162
	AM./MMA	Outline restorations of early stages of the development of Leptoplastus salteri	249
	1.	Diagrammatic elevation of the Hökulvikurgil dyke	326
	2.	Diagrams illustrating the sequence of the intrusions in the same	337
	3.	Graph illustrating the rate of cooling of the middle and margins of a dolerite-dyke	338
	1.	Vertical section of the Llandovery rocks in the Llandovery district	348
	2.	Sections along the lines indicated on the map (Pl. XXI).	362
	3.	\ensuremath{Map} of the southern portion of the Llandovery district .	374
	4.	Diagram illustrating the geological history of the Llandovery district	378
	-	Vertical sections illustrating the variation in thickness and in lithology of the Llandovery rocks of the Garth district	402
	_	Map illustrating the relations between the Llandovery rocks of Llandovery and those of Garth	408
	1.	Sketch-map [of parts of Sind and Baluchistan]	418
	2.	Geological map of the neighbourhood of Meting (Sind),	422
	3.	Stratigraphical column showing the sequence of the Laki Series	423
	4.	Diagrammatic cross-section from Bund Vera to Meting.	428
	5.	Horizontal cross-section of Discocyclina archiaci var.	447
Figs. 1	- 5.	Diagrams illustrating the formation of the Ancon clay pebble-bed	56–57
Fig.	6.	Diagram representing a perspective view of a block of country at Ancon	458
	7.	Mass of conglomerate in the Ancon clay pebble-bed	
	1.	Sketch-map showing the position of those parts of North Wales that have been recently re-surveyed	464

	PROC	RSS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES.	xiii
			PAGE
Fi G.	2.	Sill of microdiorite in a false-bedded 'ringer', Mynydd t' Isaf	482
	3.	Dacite, eastern flank of Cerniau	486
	4.	Diorite-porphyry from a sill in the Ffestiniog Beds, Foel Cae Poeth	486
	5.	Geological map of the district south-west of Dolgelley, and section across the same	488
	6.	Stages in the development of Rhobell Fawr	492
	7.	[Geological map of] Rhobell Fawr summit	497
	8.	Map showing detail of the north-eastern corner of the outlier	498
	9.	Geological sketch-map of Moel Cors-y-Garnedd	500
	10.	Sketch-section across Moel Cors-y-Garnedd	501
	11.	Quartz-keratophyre tuff, Moel Offrwm	504
	12.	Spilites from Dduallt and Bryniau Cogau	504
	13.	Modifications of dolerite	523
	14.	Porphyritic dolerite and dolerite-aplite	525
	15.	Twins of plagioclase in dolerite-aplite, summit of Rhobell Fawr	525
	16.	Section from the lower slopes of Rhobell Fawr to	
	1.	Horizontal sections illustrating the geology of the Cader Idris range	544
	2.	Horizontal sections illustrating the geological structure of the Cader Idris range and the Talyllyn valley	580
	1.	Sketch-map of Somerset and the Bristol Channel	. 596
	2.	Sketch-map of the Radstock district	. 599
	3.	Diagrams of exposures of the Lower Lias in tha	t . 600
	4.	Microscope-section of the Ironshot Limestone, Kil mersdon Road Quarry	. 602
	5.		
	6.	Diagrams of exposures of the Lower Lias at localitie west of the sections illustrated in fig. 3	s . 612
	7.		
	8.	-	
	9,		
	10.	Diagrams illustrating successive stages in the depositio of the Lower Lias	n 6 28

			PAGE
Fig.	11.	Map illustrating the denuded pre-sauzeanum folds, and showing approximately the age of the deposits upon which the Bucklandi Bed rests	629
	12.	Sutures of Arnioceras and Pararnioceras	637
	13.	Outline of the sutures of Gleviceras aff. glevense	642
	14.	Changes in the shape of the whorl in Victoriceras iridescens sp. nov.	643
	15.	Sutures of Uptonia	647
	16.	Sutures of Platypleuroceras	649
	17.	Gryphæa aff. dumortieri, G. aff. obliqua, and G. incurva var. crassirugata nov	65 3
		\mathbf{I}	AGES
Figs. 1-	-VI.	Geometrical diagrams illustrating a discussion on the form of the surface of contact between two interfering spherulites	-7 01

Dates of Issue of the Quarterly Journal for 1925.

No. 321-March 25th, 1925.

No. 322—July 4th, 1925.

No. 323—October 3rd, 1925.

No. 324-December 31st, 1925.





PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1924-25.

November 5th, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

The Names of certain Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the non-payment of the arrears of their Annual Contributions.

The List of Donations to the Library was read.

Prof. Franz Xaver Schaffer, of the State Natural History Museum, Vienna, then proceeded to deliver a lecture on The History of the Vienna Basin, of which the following is an abstract:—

After the withdrawal of the sea from Central Europe in Upper Oligocene time the transgression of the Lower Miocene (First Mediterranean Stage) took place along a narrow channel between the foot of the Alpine-Carpathian range and the old Bohemian massif, the sea reaching a height of more than 500 metres above the present sea-level. This narrow channel, which is called the 'Extra-Alpine Basin,' then underwent subsidence, resulting in a fall in the level of the sea, during which the so-called Schlier and the beds of Grund were deposited. The latter strata contain the richest subtropical molluscan fauna known in Central Europe. But the appearance of freshwater beds associated with the deposits of this shallow sea shows the interruption of former marine communications towards the west and north.

During the First Mediterranean Stage the region within the VOL. LXXXI.

Alps, where the 'Intra-Alpine Basin' is now situated, began to subside along two faults running obliquely to the strike of the folds, in a north-and-south and north-east and south-west direction. In the triangular depression between them a freshwater lake was formed, with its level at first higher than that of the sea without, but was finally invaded by the marine waters carrying a rich fauna (Second Mediterranean Stage). The sea attained a height at this time of about 450 metres above the present sea-level, and the subsidence of the floor of this shallow bay continued. A connexion existed at first with the Mediterranean across the Hungarian basin, Serbia, and the Balkan Peninsula, but in later Miocene time a considerable part of this sea was cut off, and an inland sea stretched from Vienna as far as Turkestan. This was the Sarmatian Sea, the brackish waters of which contained a very stunted and uniform fauna, and reached about 400 metres above sea-level.

Then mountain-folding took place in the Transylvanian Alps, and the large inland sea was divided into an eastern 'Pontic' and a western 'Pannonian' basin. The water-level of the latter rose to about 450 metres, the freshwater conditions became more accentuated, and the fauna still more impoverished (Pontic Stage =

Lower Pliocene).

More than 700 metres of sediments were deposited in the Intra-Alpine Basin after the Second Mediterranean Stage, during continued subsidence of its floor. Then, by an outflow through the 'Iron Gate' near Orsova, a gradual but intermittent sinking of the water-level took place, in accordance with a similar intermittent lowering of the base-level of erosion in the eastern region. Shorelines have been eroded on the borders of the basin at about 230, 200, 150, 100, and 50 metres respectively above the present riverplain. The predecessor of the Danube had its inflow on the site of the city of Vienna, and deepened its channels in accordance with the levels of the lake, depositing gravels over the terraces lying at the above-mentioned altitudes. With the deposition of the 50-metre terrace the sedimentation under lacustrine conditions came to an end, and the river eroded the soft sediments and cut lower terraces into them during Quaternary time. Of these terraces only one, that at 15 metres, is preserved within reach of the city of Vienna.

A SPECIAL GENERAL MEETING was held at 5.15 P.M. (before the Ordinary General Meeting) to elect a Member of Council and a Vice-President in the room of the late Dr. C. W. Andrews, F.R.S. A ballot was taken, and Sir Arthur Smith Woodward, LL.D., F.R.S., was elected a Member of Council and a Vice-President.

November 19th, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

George Hulme Hubbard, B.Sc., c/o the Anglo-Persian Oil Company, Ltd., Mohammerah (Persian Gulf); John Joseph Rowe, B.Sc., c/o the Niger Company (Mining Department), Tudun Wadia, Jos (Northern Nigeria); and Benjamin Seymour Redmayne Schofield, B.A., 119 East 19th Street, New York City (U.S.A.), were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT then announced the recent decease of the Society's Foreign Secretary and Past-President, Sir Archibald Getkie, K.C.B., O.M., and made special reference to the great service which he had rendered in familiarizing British geologists with the work of their colleagues in other countries. The Fellows present remained standing during this announcement.

The following communication was read:-

'On the Conditions of Deposition of the Stockdale Shales of the Lake District.' By Prof. John Edward Marr, Sc.D., F.R.S., F.G.S.

December 3rd, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Gerald Andrew, M.Sc., 15 Hawarden Avenue, Whalley Range, Manchester; Miss Eleanor Violet Colebrook, B.A., B.Sc., 45 Romilly Road West, Cardiff; William Gerald Groves Cooper, B.Sc., Gold Coast Geological Survey, Accra (Gold Coast); Percy Thomas Cox, M.A., 121a Tinakori Road, Wellington (New Zealand); Henry Christopher Curwen, Frenchwood, Arnside (Westmorland); Louis Victor Alfred Fowle, B.Sc., Hurley, St. Alban's Road, Kingston-on-Thames (Surrey); Iorwerth Griffith, Llwynderw, Tregarth, Bangor (Carnarvonshire); Robert Ferrand Paget, 28 Westgate Terrace, S.W. 10; Alan James Ruthven-Murray, B.A., Anglo-Ecuadorian Oilfields Ltd., Santa Elena, Ecuador (South America); Launcelot Potter Timmins, 174 Northfield Road, King's Norton, Birmingham; Thomas Henry Turney, B.A., 6 Harrison Road, Halifax; Walter Frederick Whittard,

B.Sc., A.R.C.S., 77 St. Anne's Hill, Wandsworth, S.W. 18; Leslie James Wilmoth, c/o the British-Burma Petroleum Company, 6 Strand Road, Rangoon (Burma); and Lambodhar Zutshi, B.Sc., 21 Cromwell Road, S.W. 7, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:-

'A Composite Dyke from Eastern Iceland.' By Miss Eileen Mary Guppy, B.Sc., F.G.S., and Leonard Hawkes, M.Sc., F.G.S.

December 17th, 1924.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Miss Catherine Mary Lewis, B.Sc., 31 Holland Park Avenue, W. 11; Edgar Francis Newton, B.Sc., 47 Chelmsford Road, Walthamstow, E. 17; and James Watson Reoch, c/o the Anglo-Persian Oil Company, Ltd., Britannic House, Finsbury Circus, E.C. 2, were elected Fellows of the Society.

The List of Donations to the Library was read.

Dr. John Downie Falconer, M.A., F.G.S., Director of the Geological Survey of Nigeria, then proceeded to deliver a lecture on the Geology of Nigeria, illustrated by maps and lanternslides. The lecturer said that the geology of Nigeria has been known in outline for the last ten or fifteen years; but systematic study dates only from the establishment of the Geological Survey in 1919. The Pre-Cambrian rocks consist of quartzites, schists, amphibolites, banded and granitoid gneisses, and foliated and partly foliated granites, pierced by tourmaline-pegmatites which are themselves in places foliated and in places tin-bearing, with the tinstone as a primary constituent. The latest component of the crystalline group is a Younger Intrusive Series, entirely nonfoliated and ranging in composition from gabbro to granite, with the latter predominating. There is no evidence for assigning to this series any other than a Pre-Cambrian age. The succession has been from basic to acid, with intrusive rhyolites and quartzporphyries immediately preceding the granite.

The Younger Granite is rich in soda, and exhibits both a biotitic and a riebeckitic facies, the latter usually local and marginal. After consolidation the granite was broken and fissured, and subjected to pneumatolytic alteration and mineralization, with the formation of tinstone, topaz, wolframite, blende, and pyrites. The older rocks adjoining the granite were also extensively fractured and broken, and subjected to similar alteration and mineralization contemporaneously with the granite. The pneumatolysis is marked by the complete absence of tourmaline, while tinstone is associated most abundantly with the alteration of the biotitic facies of the

Nigerian tinstone is thus of dual age and origin. It occurs with tourmaline as an original constituent of the older pegmatites, and with topaz in the pneumatolytic modifications of the younger granite and surrounding rocks. The granite is by far the richer source, and has shed the larger part of the tinstone which is now

being recovered from the alluvial deposits of the tinfields.

The sedimentary rocks of Nigeria consist of Cretaceous and Tertiary strata, separated by an unconformity. The former have been investigated in the vicinity of the Government colliery, and have been subdivided into four groups: the Lower Shales of marine origin, the Upper Shales of estuarine origin, the Coal Measures, and the Sandstone Group. These groups are in conformable succession, and, despite the occurrence in the Upper Shales of certain plants with Tertiary affinities, they are believed to represent

accumulations of Cretaceous age from Turonian upwards.

The Tertiary rocks have been studied along the Eastern Railway between the coalfield and the sea, and have been subdivided into a lower sandstone group, an estuarine group with a middle Eocene fauna (Bende-Ameki Beds), a lignite group, and a group of unconsolidated sands and clays (Benin Sands). There is a wellmarked unconformity between the Cretaceous and the Tertiary, and it is believed that the various groups of Tertiary rocks are also separated by unconformities. Fossiliferous Tertiary deposits have been located in other parts of Nigeria; but the classification established for the Eastern Railway cannot yet be extended to the other Tertiary areas.

The volcanic rocks of Nigeria have been investigated to some extent on the central tinfields, where an older and a younger group have been distinguished. Both are basaltic in character, and the older was subjected to considerable erosion before the effusion of the younger. Ancient river-beds with tin-bearing gravels occur

beneath both groups of volcanic rocks.

January 7th, 1925.

Dr. J. W. EVANS, C.B.E., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following Fellows, nominated by the Council, were elected Auditors of the Society's Accounts for the preceding year: HENRY DEWEY and HORACE WOOLLASTON MONCKTON, Treas.L.S.

The following communication was read:-

'The Geology of the Rhobell Fawr District (Merionethshire).' By Alfred Kingsley Wells, M.Sc., F.G.S.

Rock-specimens, microscopic sections, and fossils were exhibited by Mr. A. K. Wells, in illustration of his paper.

January 21st, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

William Edward Cooke, B. Eng., Lecturer in Mining at Sheffield University, 5 Grange Crescent Road, Sharrow, Sheffield; Janet Mitchell Marr Dingwall, M.A., B.Sc., Assistant-Lecturer in Geology, University College of South Wales & Monmouthshire, 18 Southminster Road, Cardiff; William John Evans, 38 Park Road, Barry (Glamorgan); Arthur Tindell Hopwood, M.Sc., Assistant in the Department of Geology, British Museum (Natural History), Cromwell Road, S.W. 7; Ronald Colgan Jewell, B.Sc., 61 Hornsey Lane, Highgate, N. 6; Gaston Henry Lamarque, A.M.Inst.C.E., 5 Kingsmead Road, Tulse Hill Park, S.W. 2; Arthur Raistrick, M.Sc., Brackenhurst, The Glen, Shipley (Yorkshire); the Rev. Edward Smith, D.D., The Rectory, Chadwell St. Mary, Grays (Essex); Stephen Henry Straw, M.Sc., Lecturer on Geology in the Victoria University of Manchester, Rosegarth, Moss Lane, Bramhall, near Stockport; William Elgin Swinton, B.Sc., Assistant in the Department of Geology, British Museum (Natural History), 19 Gladsmuir Road, Highgate, N. 19; and Frederick William Whitehouse, M.Sc., Sedgwick Museum, Cambridge, were elected Fellows of the Society.

The List of Donations to the Library was read.

The President then announced the recent decease of the Society's Past-President, William Whitaker, F.R.S., and referred to his long and eminent scientific career, to his abounding good-nature, and his kindness to all with whom he came into contact. The Fellows present remained standing during this announcement.

Dr. LEON WILLIAM COLLET, For Corr.G.S., Professor of Geology and Dean of the Faculty of Science in the University of Geneva, proceeded to deliver a lecture on 'The Latest Ideas

on the Formation of the Alpine Range."

In 1905 Prof. E. Argand determined in the Pennine Alps the existence of six great recumbent folds or nappes. He started from the notion of the geosyncline, so splendidly developed by Dr. E. Haug, and destined to remain for all time the basal conception of tectonics. His equipment included a very detailed stratigraphical knowledge, and, armed with this, he has succeeded in straightening out the recumbent folds, and in thus reconstituting the Pennine region at various stages of its development, when the general geosynclinal depression was subdivided by geanticlinal ridges.

On the base of Argand's results Dr. R. Staub found in the northeastern part of the Swiss Alps the same tectonic elements, covered by six higher nappes belonging more to the type of the 'thrustmasses' of the North-Western Highlands of Scotland than to the type of the recumbent folds of the Pennine Alps. This new series of nappes has been named by Staub the Austrides, for they

form the main part of the Austrian Alps.

For many years the Austrian geologists regarded the Tauern as a gneissic massif surrounded by schists and shales. Lately Prof. L. Kober, of the University of Vienna, has recognized instead a window: that is, a horizontal cut, due to erosion, in the nappes of the Austrides, which reveals deeper nappes belonging to the Pennine series. Therefore, this discovery shows that the nappes of the Austrides have been thrust over the Pennine nappes in the Austrian Alps, just as in the north-eastern part of Switzerland.

This was excellent, but a satisfactory co-ordination of the work done by Austrian and Swiss geologists was needed. That was accomplished at the end of last year by Dr. Staub. He published a memoir on the formation of the whole Alpine chain, from the French Alps to the Austrian, including the Swiss Alps, and

summarized his views in a splendid geological map.

A capital point is the employment of Wegener's ideas on the drifting of continental masses, to explain the movement of the Hinterland towards the Foreland of the geosyncline. Foreland and Hinterland constitute the boundaries of the great Alpine geosyncline: together they recall the two jaws of a vice. Prof. P. Termier, Director of the French Geological Survey, has shown how the approach of the two jaws has led to the compression of the geosyncline, and thus to the development of the Alpine chain. Prof. Argand, at the Session of the International Geological Congress in Brussels, showed that the nappes of the Austrides belong to the Hinterland: that is, to Africa or Gondwanaland. Therefore the Austrides, with the Préalpes, represent a small part of Africa resting on Europe or Eurasia. These important views are accepted by Dr. Staub and by the Lecturer. Alpine tectonics are a great support to Wegener's theory on the drifting of continental masses.

The Lecturer presented the results arrived at, with the help of an enlargement of Dr. Staub's geological map, drawn by his Assistants for this lecture and others that he had arranged to give at the University of Cambridge, at the University College of Wales, Aberystwyth, and to the Geological Society of Edinburgh.

At the end of the lecture Prof. Collet showed lantern-slides with views of the Pennine Alps (to illustrate Argand's standard work) and views of the Mont Blanc Massif, where he has been working in recent years with his collaborators, Prof. Reinhard and Dr. Parejas.

February 4th, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Richard Eldred Gubbins, A.R.C.S., The Rectory, Prince's Risborough (Buckinghamshire); Robin John Tillyard, M.A., Sc.D., D.Sc., F.L.S., Director of the Biological Department, Cawthron Institute, Nelson (New Zealand); and Miss Margaret Carter Tuck, B.Sc., Woodstreet Farm, Clyffe Pypard, Swindon (Wiltshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:-

'The Petrology of the District between Nevin and Clynnog-fawr (Carnaryonshire).' By Albert Heard, M.Sc., Ph.D., F.G.S.

Models of twenty-two famous diamonds were exhibited by the Rev. H. N. Hutchinson, M.A., F.G.S.

ANNUAL GENERAL MEETING.

February 20th, 1925.

Dr. John William Evans, C.B.E., LL.B., F.R.S., President, in the Chair.

REPORT OF THE COUNCIL FOR 1924.

During the past year 53 new Fellows were elected into the Society (10 more than in 1923), and 1 Fellow was reinstated. Of the Fellows elected in 1924, 42 paid their Admission Fees before the end of that year, and of the Fellows who had been elected in the previous year 10 paid their Admission Fees in 1924, making the total accession of new and reinstated Fellows during 1924 amount to 53 (3 more than in 1923).

Allowing for the loss of 49 Fellows (21 deceased, 14 resigned, and 14 removed), it will be seen that there is an increase of 4 in the number of Fellows (as compared with a decrease of 3 in

1923). The total number of Fellows is, therefore, at present 1280, made up as follows:—Compounders 188 (the same as in 1923); Contributing Fellows 1083 (4 more than in 1923); and Non-

Contributing Fellows 9 (the same as in 1923).

With regard to the Lists of Foreign Members and Foreign Correspondents, it will be remembered that, at the end of 1923, there were 2 vacancies in the former List and 5 in the latter. The Council regrets to have to announce the decease of 3 Foreign Correspondents (Dr. Maurice Cossmann, Prof. J. J. Stevenson, and Dr. Thorvaldr Thoroddsen); there are consequently now 8 vacancies in the List of Foreign Correspondents, besides the 2 in the List of Foreign Members.

The Receipts of the year, including the interest on the Sorby and Hudleston Bequests, as also the interest transferred from the Prestwich and Barlow-Jameson Funds, amounted to £4270 4s. 4d., and the Expenditure to £4156 9s. 9d. The year opened with a deficit of £63 12s. 11d., and closed with a balance in hand of

The Council regrets that it does not see its way to resume the free distribution of the Quarterly Journal to the Fellows in 1925; but it hopes that, before long, the financial position will justify it in adopting this course.

A Special General Meeting was held on November 5th, 1924, at which Sir Arthur Smith Woodward was elected a Member of Council and a Vice-President, in place of Dr. C. W. Andrews,

deceased.

The President was nominated as Delegate to the celebration of the Kelvin Centenary, and to the Jubilee celebration of the Physical Society. With Miss G. L. Elles he was also nominated as Delegate to the celebration of the coming-of-age of Leeds University. Prof. P. G. H. Boswell was appointed Delegate to the Liverpool Congress of the Royal Sanitary Institute; Mr. G. Dollfus, For.M.G.S., represented the Society at the Centenary celebration of the Societé Linnéenne de Normandie; Dr. J. S. Flett was nominated as Delegate to the Centenary celebration of the Franklin Institute; and Mr. W. Campbell Smith as Delegate to the Conference of Corresponding Societies of the British Association.

The Society's Apartments have been used for General Meetings, and for Council or Committee Meetings, during the past year by the British Academy, the Institution of Mining Engineers, the Institution of Mining & Metallurgy, the Institution of Water Engineers, the Society of Engineers, the Mineralogical Society, the Palæontographical Society, the Prehistoric Society of East

Anglia, and the Geologists' Association.

A framed portrait of Leonardo da Vinci was presented by

Prof. E. J. Garwood.

A collection of minerals, which at one time formed part of the Society's collections, was presented through the intermediary of the Department of Minerals of the British Museum to the newly-established Science Department of Durham University, a selection having been made for retention in the British Museum collections. A complete set (so far as available) of the Quarterly Journal was presented to the Geological Survey of Japan, in replacement of the set destroyed in the great earthquake of September 1923.

The investigation of the bone-caves of the Gower Peninsula, which Prof. W. J. Sollas had proposed to undertake with the assistance of the Gloyne Outdoor Geological Research Fund,

proved to be impracticable, and has been abandoned.

The only research at present receiving assistance from that Fund is that which has for its object the investigation of the nature and succession of the beds which underlie the Red Chalk near South Ferriby, on the Humber, by means of certain excavations conducted by the Hull Geological Society. Two pits were sunk on the foreshore; but the observations possible in these were inconclusive, and it is proposed to sink a small pit above the beach in the course of 1925. Mr. G. W. Lamplugh is acting as supervisor of the work, on behalf of the Council.

A circular issued to all Societies interested in geological and archæological research, bespeaking their support in a protest to be made against the cessation of the issue of quarter-sheets of the 6-inch Ordnance Survey maps, met with widespread response. The Director-General of the Ordnance Survey has recently informed the Council that the speedy resumption of the issue of these quarter-sheets is contemplated.

Mr. R. U. Sayce, who received the Proceeds of the Daniel-Pidgeon Fund for 1913, has returned the amount, as he found it impossible to carry out the work for the prosecution of which the

grant was made.

The Proceeds of the Daniel-Pidgeon Fund for 1924 have been awarded to Dr. Kenneth Stuart Sandford, University College, Oxford, who proposes to investigate the Pleistocene Geology of the Thames Basin, west of Goring Gap.

Further, the following Awards of Medals and Funds have

been made :-

The Wollaston Medal is awarded to Mr. George William Lamplugh, in recognition of his researches 'concerning the mineral structure of the Earth', especially in connexion with Stratigraphy and Glaciology.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Dr. Herbert Henry Thomas, as an acknowledgment of the value of his re-

searches on the Petrology of the British Isles.

The Lyell Medal, together with a sum of Twenty-five Pounds from the Lyell Geological Fund, is awarded to Mr. John Frederick Norman Green, in recognition of the value of his researches among the older rocks of the British Isles.

The Bigsby Medal is awarded to Mr. Cyril Workman Knight, as an acknowledgment of his eminent services to Geology, and more especially of his work on the Pre-Cambrian rocks and on the

metalliferous deposits of Ontario.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Dr. Alfred Brammall, in recognition of the value of his researches on metamorphism and on the granites of Dartmoor.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Dr. Arthur Elijah Trueman, in recognition of the value of his researches on the Palacontology of the Invertebrata.

A Moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Dr. James Allan Thomson, in recognition of the value of his researches on the Petrology and Palæontology of New Zealand.

A second Moiety of the Balance of the Proceeds of the Lyell Geological Fund is awarded to Dr. William Alfred Richardson, in

recognition of the value of his researches in Petrology.

REPORT OF THE LIBRARY COMMITTEE FOR 1924.

The work in connexion with the Library has shown no signs of diminution during the past year, as increasing use has been made of the Library by Fellows and others, for purposes both of reference and borrowing of books, and also for enquiries of the most varied

description.

The accessions during the year were somewhat fewer than in the preceding year. This is explained by the fact that in 1923 several large collections of books and pamphlets were presented. During 1924, the Library received by donation 96 volumes of separately published works and 442 pamphlets; also 127 complete volumes and 305 parts of serial publications, 234 volumes and 342 parts of the publications of Geological Surveys and other public bodies, and 12 volumes of weekly periodicals. The more important of these have already been enumerated in the Abstracts of Proceedings, but special attention may be drawn to the Reports of the British Antarctic (Terra Nova) Expedition, 1910-13; to the monograph on the Vesuvius Eruption, by F. A. Perret, published by the Carnegie Institution of Washington; to Memoir No. 16 of the New York State Museum—'Devonian Crinoids of the State of New York', by Winifred Goldring; to Dr. Charles Davison's 'History of British Earthquakes'; and to a typescript copy of the foolscap lithographed issue of Alexander Burnes's report on the Allah Bund, 1827-28: this typescript was presented by Mr. R. D. Oldham, who states that there appears to be no other copy of this issue of the report in this country.

The Society has now resumed exchange relations with the Geological Committee of Russia, and the Library has received from that Committee a number of memoirs on the geology of Russia and Siberia. Several reports dealing with the economic geology of Nyasaland have been received from the Geological Survey of that Protectorate. The new French Geological Survey of Alsace-Lorraine has also sent its publications in exchange for the Society's

Quarterly Journal.

The additions mentioned in the foregoing paragraphs represent the donations of 133 Government Departments and other public bodies, 144 Societies and Editors of periodicals, and 141 Personal Donors.

The accessions of geological maps show a large increase over preceding years, 390 sheets having been received. Of these, 20 were sheets of the 1-inch Geological Survey map of England and Wales, and 16 were sheets of the 1-inch map of Scotland. In addition, a large number of sheets of the 6-inch Geological Survey maps of both these countries are included in the above-mentioned total. Other donations under this heading included 7 sheets of maps presented by the Geological Commission of Switzerland, among which was a tectonic map of the Alps on the scale of

1:1,000,000, by R. Staub; a new edition, edited by C. Papp, of Loczy's geological map of Hungary, on the scale of 1:900,000; a manuscript map of British Honduras, on a scale of 1 inch=8 miles (or 1:506,880); and 6 sheets of the Petroleum Research Survey of the Sinaitic Peninsula, on the scale of 1:125,000, presented by the Survey Department of Egypt.

Purchases during 1924 included 9 volumes and 35 parts of works published separately, and 31 volumes and 30 parts of serial publications. Among them, the following may be mentioned:—

M. Boule—'Fossil Men', English Edition, 1924; A. Rosenbusch—'Mikroskopische Physiographie', 5th Edition, by E. A. Wülfing, Vol. i, pts. 1 & 2; A. Wegener—'The Origin of Continents & Oceans' (English translation); S. von Bubnoff—'Die Gliederung der Erdrinde'; J. Weigelt—'Angewandte Paläontologie & Geologie der Flachseegesteine & das Erzlager vom Salzgitter'; W. Sörgel—'Diluviale Flussverlegungen & Krustenbewegungen'; also the 'Zeitschrift für Vulkanologie' Vols. i–viii and Supplementary Vols. i–iv.

Continued endeavour has been made to overtake the large arrears of binding on hand. This has been so far successful that the binding of all the serials and separate works in greatest demand by the Fellows is complete. There still remain some of the less-used serials, and a number of periodicals of so little geological interest that the question of their retention in the Library is one which will have to be seriously considered ere long, as the Library is fast outgrowing the available accommodation. A certain amount of repair work has also been undertaken during the year, a total of 208 volumes passing through the hands of the binders.

Books borrowed from the Library during 1924 numbered 1124. Of these 737 were taken personally by the borrowers, and 387

were sent through the post.

Much work was done on the Card-Catalogue, the Author-lists for 1915–19 and for 1923 being incorporated therein. The subject-and-locality cards for 1914–1919 still remain to be sorted in. The Catalogue now contains a complete list of Authors and titles of papers up to the end of 1923, the subject-and-locality catalogue stopping at 1913. The List of Geological Literature for 1923 (list of Authors & titles of works only) was passed through the press during the early part of 1924, and the manuscript of the 1924 List was compiled during that year.

The Expenditure incurred on the Library was as follows (the figures in parentheses denote, for purposes of comparison, the

amounts spent during 1923) :-

For Books and Periodicals For Binding and Map-Mounting For Card-Cataloguing	70	5 17 14	8	(74 7 (85 12 (1 10	0) 5)
	£165	16	11	(161 10	0)

The appended Lists contain the Names of Government Departments and other Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review :-

I. GOVERNMENT DEPARTMENTS AND OTHER PUBLIC BODIES.

Alabama.—Geological Survey. Montgomery (Ala.). Alsace-Lorraine.—Service de la Carte Géologique. Strasbourg.

American Museum of Natural History. New York. Australia, Government of the Commonwealth of. Australia (South), etc. See South Australia, etc. Austria.—Geologische Bundesanstalt. Vienna. Barcelona.-Museu de Ciències Naturals. Bavaria.-Oberbergamt & Geologische Landesuntersuchung. Munich. Belgium.—Académie Royale des Sciences, des Lettres & Beaux-Arts de Belgique. Belgrade.-Institut Géologique de l'Université. Bergens Museum. Bergen. Berlin.-Preussische Akademie der Wissenschaften. Bristol Museum & Art Gallery. British Columbia.—Ministry of Mines. Victoria (B.C.). Brussels.—Musée Royal d'Histoire Naturelle de Belgique.
California.—Academy of Sciences. San Francisco.
—, University of. Berkeley (Cal.).
Cambridge (Mass.).—Museum of Comparative Zoology in Harvard College. Canada.—Geological Survey. Ottawa.

Department of Mines. Ottawa. Canadian Pacific Railway Company. London. Cape Town.-South African Museum.

Cape Town.—South African Museum,
Cardiff.—National Museum of Wales,
Chicago.—Field Museum of Natural History,
China.—Geological Survey. Peking.
Córdoba (Argentine Republic).—Academía Nacional de Ciencias,
Czecho-Slovakia.—Státního Geologického Ústavu. Prague.

Denmark.—Kommission for Ledelsen af de Geologiske & Geografiske Undersögelser i Grönland. Copenhagen.

Dublin.—Royal Irish Academy.

Egypt.—Ministry of Finance (Survey Department). Cairo.

Federated Malay States.—Government Geologist. Kuala Lumpur.

Finland.—Finlands Geologiska Undersökning. Helsingfors. France.—Ministère de l'Instruction Publique. Paris.

Muséum d'Histoire Naturelle. Paris. Service Hydrographique de la Marine.

Gold Coast.—Geological Survey. Accra. Mining Department. Accra.

Great Britain.—Colonial Office. London.
—. Geological Survey. London.
—. Imperial Institute. London.

- . Imperial Mineral Resources Bureau, London. Mines Department. London.

Holland.—Departement van Kolonien. The Hague.

Rijksopsporing van Delfstoffen. The Hague.
Honolulu.—Hawaiian Volcano Observatory.

Hungary.—Geologische Reichsanstalt. Budapest.

Hungary.—Geologische Reichsanstalt. Budapest.
Illinois.—Geological Survey. Urbana (III.).
India.—Geological Survey. Calcutta.
——. Trigonometrical Survey. Dehra Dun.
Ireland.—Geological Survey. Dublin.
Italy.—R. Comitato Geologico d'Italia. Rome.
Japan.—Earthquake-Investigation Committee. Tokio.
——. Geological Survey. Tokio.
——. National Research Council. Tokio.
Kansas University. Lawrence (Kan.).

Kentucky.-Geological Survey. Frankfort (Ky.).

La Plata.—Museo de La Plata. Lausanne.—University of.

London.—British Museum (Natural History).

—. Metropolitan Water Board. Louvain.—Institut Géologique de l'Université.

Madrid.-Museo de Ciencias Naturales.

Real Academía de Ciencias Exactas, Físicas & Naturales.

Maryland Geological Survey. Baltimore.

Mexico.—Instituto Geológico. Mexico City.

—. Secretaria de Industria, Comercio & Trabajo. Mexico City.

Milan.—Reale Istituto Lombardo di Scienze & Lettere.

Missouri.—Bureau of Geology & Mines. Rolla. Moscow.—'Lithogæa' Institute.

Munich.—Bayerische Akademie der Wissenschaften. Mysore.—Geological Department. Bangalore. New South Wales.—Department of Mines. Sydney.

New South Wales.—Department of School School Survey. Sydney.

New York State Museum. Albany (N.Y.).

New Zealand.—Board of Science & Art. Wellington.

Wellington. Wellington.

Department of Lands & Surveys. V
 Department of Mines. Wellington.
 Dominion Museum. Wellington.
 Geological Survey. Wellington.

Nigeria.—Geological Survey. Norway.—Geologiske Undersökelse. Oslo.

Norwich Castle Museum Committee.

Nyasaland Protectorate.—Geological Survey Department. Zomba. Ohio.—Geological Survey. Columbus.

Ontario.—Department of Mines. Toronto. Oregon.—University of. Eugene.

Padua.—Istituto Geologico della R. Università.

Paris.-Académie des Sciences.

Peking.—Geological Institute of the National University.

Peru.-Ministerio de Fomento. Lima.

Philippine Is.—Department of the Interior; Bureau of Science. Manila.

Pisa.—Università Toscane. Warsaw.

Poland.—Service Géologique. Warsav Portici.—Reale Scuola di Agricoltura. Portugal.—Servico Geológico. Lisbon.

Prussia. Preussische Geologische Landesanstalt. Berlin.

Quebec.—Department of Colonization, Mines, & Fisheries. Queensland.—Department of Mines. Brisbane.

— . Geological Survey. Brisbane.
— . Irrigation & Water-Supply Commission. Brisbane.
Rhodesian Museum. Bulawayo.

Rio de Janeiro.-Museu Nacional.

Rome.—Reale Accademia dei Lincei.

Rumania.—Academia Română. Bucarest. Russia.—Comité Géologique. Petrograd.

Vladivostok.

Russian Far East.—Geological Committee. Scotland.—Geological Survey. Edinburgh. Sendai.—Tôhoku Imperial University.

South Africa.—Department of Mines. Pretoria.
—. Geological Survey. Pretoria.
South Australia.—Department of Mines. Adelaide.

Geological Survey. Adelaide.

Southern Rhodesia.—Geological Survey. Salisbury.

Spain.—Instituto Geologico. Madrid. Sweden.—Sveriges Geologiska Undersökning. Stockholm. Switzerland.—Geologische Kommission der Schweiz. Berne.

Tasmania.—Geological Survey. Hobart.

. Secretary for Mines. Hobart.
Uganda.—Geological Survey. Entebbe.
United States.—Department of Commerce, Coast & Geodetic Survey. Washington (D.C.).

Geological Survey. Washington (D.C.).

United States.—National Academy of Sciences & National Research Council.

Washington (D.C.).

- National Museum. Washington (D.C.). Vermont.—Geological Survey. Burlington (Vt.).

Victoria (Australia). - Geological Survey. Melbourne.

Vienna.-Akademie der Wissenschaften. Naturhistorisches Museum.

Washington University. St. Louis (Mo.). Washington (D.C.).—Carnegie Institution.

— Geophysical Laboratory.
— Smithsonian Institution.

Western Australia.—Department of Mines. Perth.

—. Geological Survey. Perth. Yale University.—Peabody Museum. New Haven (Conn.).

II. SOCIETIES AND EDITORS.

Adelaide.-Royal Society of South Australia.

Basel.—Naturforschende Gesellschaft. Belfast.—Natural History Society. Bergen.—'Naturen.'

Berlin .- Deutsche Geologische Gesellschaft.

-. Zeitschrift für Berg-, Hütten-, & Salinenwesen. Berne.—Schweizerische Naturforschende Gesellschaft.

Bombay Branch of the Royal Asiatic Society.

Bordeaux.—Société Linnéenne.

Boston (Mass.).—American Academy of Arts & Sciences. Bristol Naturalists' Society.

Brussels.—Société Belge de Géologie.

Société Royale Zoologique & Malacologique de Belgique.

Budapest.-Hungarian Geographical Society Ungarische Geologische Gesellschaft.

Buenos Aires. - Sociedad Cientifica Argentina.

Caen. - Société Linnéenne de Normandie. Calcutta.—Asiatic Society of Bengal.

—. Institute of Engineers (India).

Cambridge Philosophical Society.

Cape Town.-Royal Society of South Africa.

South African Association for the Advancement of Science.

Cardiff.—South Wales Institute of Engineers. Chicago.—'Journal of Geology.'

Copenhagen.-Dansk Geologisk Forening.

Córdoba (Spain).—Real Academia de Ciencias de Córdoba.

Denver.-Colorado Scientific Society.

Des Moines.—'The Pan-American Geologist.'

Dijon.—Académie des Sciences

Dorchester .- Dorset Natural History & Antiquarian Field-Club.

Dorpat.-Naturforschende Gesellschaft.

Dublin.—Royal Dublin Society.

Edinburgh.—Royal Scottish Geographical Society.

— . Royal Society. Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.

Fribourg.—Société Fribourgeoise des Sciences Naturelles.

Geneva.-Société de Géographie.

-. Société de Physique & d'Histoire Naturelle.

Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde, Gloucester.—Cotteswold Naturalists' Field-Club.

Hague, the.-Société Hollandaise des Sciences.

Halifax (Nova Scotia).—Nova Scotian Institute of Science.

Halle a. d. Saale.—Zeitschrift für Praktische Geologie.

Hereford.—Woolhope Naturalists' Field-Club. Hertford.—Hertfordshire Natural History Society. Johannesburg.—Geological Society of South Africa.

Lausanne.—Société Vaudoise des Sciences Naturelles.

```
Leeds Philosophical & Literary Society.
 Leeds.—Yorkshire Geological Society
 Leicester Literary & Philosophical Society.
 Leipzig.—Zeitschrift für Krystallographie.
  Lexington.—Kentucky Academy of Science.
Liége.—Société Géologique de Belgique.
Lima.—Asociación Peruana para el Progreso de la Ciencia.
 Liverpool Geological Society.
 London.—British Association for the Advancement of Science.
  —. Chapman & Hall, Ltd.—. Chemical Society.
 The Chemical Revision.
         'Fuel.
         'The Geological Magazine.'
Geologists' Association.
Institution of Civil Engineers.

    Institution of Mining Engineers.

    . Institution of Mining & Metallurgy.
  - Institution of Water Engineers.
          Iron & Steel Institute.
          Linnean Society
   - Linnean Society.

'The London, Edinburgh, & Dublin Philosophical Magazine,'
- Mineralogical Society.
          'The Mining Journal.'
         'The Mining Magazine.'
          'Nature.'
  'Oil-Engineering & Finance.'
         'The Quarry.'
'Roads & Road Construction.'
  - Royal Agricultural Society.
  - Royal Astronomical Society.
  - Royal Geographical Society.
          Royal Institution.
Royal Meteorological Society.
         Royal Microscopical Society.
   - Royal Photographic Society.
   --- Royal Society.
  --- Royal Society of Arts.
  -- Society of Engineers.
  — Victoria Institute.
— 'Water.'
  —. Zoological Society.

Manchester. - Literary & Philosophical Society.

Marlborough.-Marlborough College Natural History Society.
  Melbourne (Victoria).—Australasian Institute of Mining & Metallurgy.
  - Royal Society of Victoria.
          'The Victorian Naturalist.
  Mexico.—Sociedad Científica 'Antonio Alzate.'
  Milan.—Società Italiana di Scienze Naturali.
Naples.—Accademia delle Scienze Fisiche & Matematiche.
  Newcastle-upon-Tyne.—University of Durham Philosophical Society.
New Haven (Conn.).—Connecticut Academy of Arts & Sciences.
          'The American Journal of Science.'
   New York.—Academy of Sciences.
    - American Institute of Mining & Metallurgical Engineers.
  Northampton.-Northamptonshire Natural History Society.
   Norwich.—Prehistoric Society of East Anglia.
  Oslo.-Norsk Geologisk Forening.
  —. Nyt Magazin for Naturvidenskaberne.
Ottawa.—Royal Society of Canada.
  Oxford University Press.
  Paris.—Annales des Mines.
——. Société Géologique de France.
```

Peking.—Geological Society of China.

Penzance.—Royal Geological Society of Cornwall. Perth.—Perthshire Society of Natural Sciences. Philadelphia.—Academy of Natural Sciences.

-. American Philosophical Society.

Plymouth.—Devonshire Association for the Advancement of Science.

Rennes.—Société Géologique & Minéralogique de Bretagne. ——. Société Scientifique et Médicale de l'Ouest. Rochester, N.Y.—Rochester Academy of Science.

Rome.—Società Geologica Italiana. Rugby School Natural History Society.

Santiago de Chile.—Sociedad Nacional de Minería.
Stockholm.—Geologiska Förening.

. K. Svenska Vetenskapsakademien.
Stratford.—Essex Field-Club.

Stuttgart.-Centralblatt für Mineralogie, &c.

Sydney (N.S.W.).—Linnean Society of New South Wales.

Royal Society of New South Wales.

Toronto.-Royal Canadian Institute.

Torquay Natural History Society.

Toulouse.—Société d'Histoire Naturelle. Turin.-Reale Accademia delle Scienze.

Upsala.—Geological Institution of the University. Vienna.—Geologische Gesellschaft.

Berg- & Hüttenmännisches Jahrbuch.

Zoologisch-Botanische Gesellschaft,

Washington (D.C.).—Geological Society of America. Wellington (N.Z.).—New Zealand Institute. Wiesbaden.—Nassauischer Verein für Naturkunde.

York .- Yorkshire Philosophical Society.

III. PERSONAL DONORS.

Anderson, E. M. Armstrong, L. Assmann, P.

Bamber, Miss A. E. Bekker, H. Bond, G. C. Born, A. Briquet, A. Brodrick, H. Broili, F. Butler, H.

Cameron, W. E. Carpentier, A. Cayeux, L. Charlesworth, J. K. Clark, E. K. Clarke, E. de C. Collet, L. W. Cox, L. R. Cullis, C. G. Curzon of Kedleston, Marquis, Cvijič, J.

Daly, R. A.
David, Sir T. W. E.
Davies, G. M.
Davison, C.
Davison, E. H.
Dix, Miss Emily.
Dixey, F.
Dobrowolski, A. B.
Dollfus, G. F.
Dubois, G.
Dunbar, C. O.
Duparc, L.

Earle, K. W. Edwards, W. N. Erdtman, O. G. E. Evans, J. W.

Fabiani, R. Flink, G. Fourmarier, P. Freire d'Andrade, C.

Giffard, H. P. W. Goldschmidt, V. M. Gregory, H. E. Gregory, J. W. Groves, J. Guareschi, P. Harmer, Sir Sidney F. Harrison, Sir John B. Haughton, S. H. Hayward, F. N. Henderson, J. Hobson, B. Högbom, A. G. Howchin, W. Huntoon, L. D.

Jillson, W. R. Johnston, Miss M. S. Jones, W. R.

Kayser, E. Keyes, C. R. King, W. W.

Lacroix, A. Lumplugh, G. W. Lee, G. W. Linck, G. Longstaff, Mrs. M. J. Louderback, G. D.

Marwick, J.
Matley, C. A.
Matousek, O.
Maude, A.
Merrett, E. A.
Merrill, G. P.
Miller, W. G.
Mitchell, J.
Moir, J. R.
Molengraaff, G. A. F.
Moule, A. C.

Nelson, W. A. Nopcsa, Baron F. North, F. J.

Oldham, R. D. Osborn, H. F. Ower, L. H.

Paréjas, E. Parkinson, J. Parry, T. W. Penzer, N. M. Plymen, G. H. Preller, C. S. du R. Pringle, J. Rastall, R. H.
Reid, Mrs. E. M.
Reynolds, S. H.
Richards, H. C.
Richardson, R. K.
Richardson, W. A.
Rogers, A. W.
Rogers, I.
Ross, C. C.
Rusu, D.

Sacco, F.
Sargent, H. C.
Sawyer, A. R.
Schaffer, F. X.
Scott, D. H.
Scrivenor, J. B.
Sefve, T.
Seward, A. C.
Shannon, E. V.
Shannon, W. G.
Sheppard, T.
Sherlock, R. L.
Simionescu, J.
Smith, W. Campbell.
Spath, L. F.
Speight, R.
Stanley, E. R.
Stelbing, W. P. D.

Taber, S.
Tammekaun, A.
Termier, P.
Thomas, A. O.
Thompson, B.
Thomson, J. A.
Tonks, L. H.
Trueman, A. E.
Tyrrell, G. W.

Vaughan, T. W. Vendl, A.

Wallis, F. S. Walther, K. Washington, H. S. Weeks, W. G. Whitehead, T. H. Wiman, C. Withers, T. H. Wray, D. A. Wright, W. B.

List of Donors to the Voluntary Publication Fund in 1923 and 1924.

Adams, F. D. Ami, H. M. Andrew, A. R. Ashcroft, F. N.

Baden-Powell, D. F. W. Bailey, E. B.
Barrow, G.
Berrose, H. H.
Berry, J.
Blizard, J. H.
Boswell, P. G. H.
Boulton, W. S.
Brammall, A.
Brown, T. W.
Buckman, S. S.
Burton, E. St. J.
Butler, G. W.

Cadell, H. M.
Chandler, Miss M. E. J.
Cobbold, E. S.
Cowan, T. W.
Cox, A. H.
Crosfield, Miss M. C.
Cullis, C. G.

Davies, A. M. Dewhurst, T. Dunn, E. J.

Elles, Miss G. L. Engleheart, F. H. A. Evans, J. W.

Farrar, A. Fearnsides, W. G. Fleck, H. Flett, J. S. Garwood, E. J. Goodyear, Miss E. Gordon, W. T. Grabham, G. W. Green, J. F. N. Greenly, E. Gregory, J. W.

Harker, A. Hartley, J. J. Hayden, Sir Henry H. Herries, R. S. Horne, J. Hume, W. F.

Jehu, T. J. Jones, O. T.

King, W. B. R.

Lake, P.
Lamplugh, G. W.
Lapworth, H.
Longden, G. A.
Longstaff, Mrs. M. J.

MacAlister, D. A. MacMillan, W. E. F. McRobert, R. W., Lady. Matley, C. A. Metcalfe, A. T. Middlemiss, C. S. Miller, W. G. Montag, E. Murray, E. O. Nicholas, T. C. Nicholson, E. D. Noel, E.

Ogilvie, Sir Francis G. Oldham, R. D. Owen, L.

Parkinson, J. Pascoe, E. H. Pearse, R. Pullar, L.

Raisin, Miss C. A. Raw, F. Reid, Mrs. E. M. Reynolds, S. H. Richardson, W. A. Robertson, J. R. M. Robling, G. Rogers, A. W.

Simmons, W. C. Smith, B. Sollas, W. J. Stenhouse, A. G. Strahan, Sir Aubrey. Stuart, D. M. D.

Teall, Sir Jethro J., H. Tunbridge, E. W. Turner, H. W.

Watt, W. R. Watts, W. W. Whitaker, W. Wills, L. J. Wright, F. E. COMPARATIVE STATEMENT OF THE NUMBER OF THE SOCIETY AT THE CLOSE OF THE YEARS 1923 AND 1924.

	Dec. 31st, 19	23. Dec	
Compounders	188		188
Contributing Fellows			1083
Non-Contributing Fellows			9
	· —		
	1276		1280
Foreign Members	, 38		38
Foreign Correspondents		******	32
	1349		1350

Comparative Statement, explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the Years 1923 and 1924.

Number of Compounders, Contributing, and Non- Contributing Fellows, December 31st, 1923 }	1276
Add Fellows elected during the former year and paid in 1924	10
$A\bar{d}d$ Fellows elected and paid in 1924	42
Add Fellow reinstated	1
-	1329
Deduct Compounders deceased 2 Contributing Fellows deceased 19	
Contributing Fellows resigned 14	
Fellows removed in accordance with Sect. VI, Art. 5, of the Bye-Laws	
All. 9, of the Dye Bane.	49
	1280
Number of Foreign Members and Foreign Correspondents, December 31st, 1923	
respondents, December 31st, 1923	
	70
	1350

DECEASED FELLOWS.

Compounders (2).

Danby, T. W. [elected in Scott, D. A. [el. 1872].

Contributing Fellows (19).

Andrews, C. W. [elected in 1894].
Beach, A. W. [el. 1899].
Burls, H. T. [el. 1880].
Church, R. W. [el. 1910].
Cole, G. A. J. [el. 1881].
Foster, D. [el. 1924].
Garrard, J. J. [el. 1907].
Geikie, Sir Archibald [el. 1859].
Grantham, R. F. [el. 1892].
Jamieson, A. W. [el. 1913].

Jordan, K. [el. 1865]. Kidston, R. [el. 1883]. Maclay, W. [el. 1902]. Pickering, G. [el. 1915]. Teall, Sir Jethro J. H. [el. 1873]. Walford, E. A. [el. 1882]. Walker, Sir Byron E. [el. 1891]. Wilson, J. R. R. [el. 1907]. Woolacott, D. [el. 1897].

Fellows Resigned (14).

Allsebrook, G.
Bellamy, C. V.
English, T.
Greenwell, G. C.
Haselhurst, S. R.
Lock, S. E. J.
May, J.

Moir, J. R.
Nairne, C.
Ord, W. T.
Roberts, R. W. B.
Robinson, P. L.
Terrey, E. W.
Ward, T. H.

Fellows Removed (14).

Abelspies, J. F. C. Armitage, R. W. Auty, H. Baldwin-Wiseman, W. R. Henderson, F. Y. Johnson, H. E. Lee, Y. Y. Legrand, P. Le Mesurier, G. J. B. Narke, G. G. Ricketts, H. W. Shrager, A. L. Sidebotham, C. H. Temby, E. T.

Fellows Elected (52)

Andrew, G. Baldry, R. A. Bamber, Miss A. E. Barnard, R. Bishopp, D. W. Boston, Lord. Bradshaw, E. J. Bulman, O. M. B. Canning, W. F. Coe, L. C. Colebrook, Miss E. V. Collins, W. I. Cornes, H. W. Curwen, H. C. Davies, L. M. Dunn, J. A. Edgell, L. F. A. Foster, D. H. Grange, L. I. Griffith, I. Guppy, Miss E. M. Hancock, J. Hayward, H. A. Herbage, D. L. Holmes, S. John, D. G.

Jones, J. R. Keep, C. E. Latter, M. P. Lewis, Miss C. M. Lindeman, H. S. R. Mason, M. H. Pardoe, J. W. Parkinson, D. Perl, A. Phemister, J. Smithson, F. Southwell, C. A. P. Stockley, G. M. Stubblefield, C. J. Tapp, W. M. Thomas, M. L. Timmins, L. P. Tomalin, W. G. C. Tomlinson, Miss M. E. Turney, T. H. Verteuil, J. P. de. Watson, D. M. Whittard, W. F. Wilkins, L. G. Williams, E. Williams, H.

FOREIGN CORRESPONDENTS DECEASED (3).

Cossmann, Dr. A. E. M. Stevenson, Prof. J. J.

Thoroddsen, Dr. T.

After the Reports had been read, it was resolved :-

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved :-

That the thanks of the Society be given to Prof. W. W. Watts, retiring from the office of Vice-President (and also from the Council), and to the other retiring Members of Council: Mr. F. N. Ashcroft, Dr. F. H. Hatch, Prof. S. H. Reynolds, and Sir Aubrey Strahan.

After the Balloting-Glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

OFFICERS AND COUNCIL.—1925.

PRESIDENT.

John William Evans, C.B.E., D.Se., LL.B., F.R.S.

VICE-PRESIDENTS.

John Smith Flett, O.B.E., M.A., LL.D., D.Sc., M.B., F.R.S. Sir Thomas Henry Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S. Prof. Albert Charles Seward, Sc.D., F.R.S., F.L.S. Sir Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

SECRETARIES.

Walter Campbell Smith, M.C., M.A. James Archibald Douglas, M.A., D.Sc.

FOREIGN SECRETARY.

Prof. John Edward Marr, M.A., Sc.D., F.R.S.

TREASURER.

Robert Stansfield Herries, M.A.

COUNCIL.

Prof. Percy George Hamnall Boswell, O.B.E., D.Sc.

Prof. Arthur Hubert Cox, D.Sc., Ph.D.

Thomas Crook.

Henry Dewey. James Archibald Douglas, M.A.,

D.Sc. Gertrude Lilian Elles, M.B.E., D.Sc. John William Evans, C.B.E., D.Se.,

LL.B., F.R.S. Prof. William George Fearnsides, M.A.

John Smith Flett, O.B.E., M.A., LL.D., D.Sc., M.B., F.R.S. Prof. William Thomas Gordon,

M.A., D.Sc., F.R.S.E.

Prof. Herbert Leader Hawkins. D.Sc.

Robert Stansfield Herries, M.A. Sir Thomas Henry Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S.

William Dickson Lang, M.A., Sc.D. Prof. John Edward Marr, M.A., Sc.D., F.R.S.

Monekton, Horace Woollaston Treas. L.S.

Tressilian Charles Nicholas, O.B.E., M.C., M.A.

Prof. Albert Charles Seward, Sc.D., F.R.S., F.L.S.

Walter Campbell Smith, M.C., M.A. Leonard James Spencer, M.A., Sc.D.

Arthur Elijah Trueman, D.Sc. Henry Woods, M.A., F.R.S.

Sir Arthur Smith Woodward, LL.D., F.R.S., F.L.S.

1923.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1924

Date of Election. Prof. Gustav Tschermak, Vienna. 1886. 1891. Prof. Charles Barrois, Lille. Prof. Waldemar Christofer Brögger, Oslo 1893. Prof. Edward Salisbury Dana, New Haven, Conn. (U.S.A.). 1894. Prof. Albert Heim, Zürich. 1896. 1898. Dr. Charles Doolittle Walcott, Washington, D.C. (U.S.A.). Prof. Emanuel Kayser, Munich. 1899. M. Ernest Van den Broeck, Brussels. 1899. M. Gustave F. Dollfus, Paris. 1900. 1900. Prof. Paul von Groth, Munich. Dr. Alexander Petrovich Karpinsky, Petrograd. 1901. Prof. Antoine François Alfred Lacroix, Paris. 1901. Prof. Albrecht Penck, Berlin. 1903. 1903. Prof. Anton Koch, Budapest. Prof. Henry Fairfield Osborn, New York (U.S.A.). 1904. Prof. Louis Dollo, Brussels. 1905. 1907. Dr. Emil Ernst August Tietze, Vienna. 1908. Prof. Bundjirô Kôtổ, Tokyo. 1909. Prof. Johan H. L. Vogt, Trondhjem. Prof. Baron Gerard Jakob De Geer, Stockholm, 1911. M. Emmanuel de Margerie, Strasbourg, 1911. 1912. Prof. Marcellin Boule, Paris. Prof. Johannes Walther, Halle an der Saale.
Prof. Friedrich Johann Becke, Vienna.
Prof. Thomas Chrowder Chamberlin, Chicago, Ill. (U.S.A.). 1913. 1914. 1914. 1914. Prof. Franz Julius Lewinson-Lessing, Petrograd. 1914. Prof. Alexis Petrovich Pavlow, Moscow. 1914. Prof. William Berryman Scott, Princeton, N.J. (U.S.A.). 1921. Dr. Frank Wigglesworth Clarke, Washington, D.C. (U.S.A.). 1921. Prof. Émile Haug, Paris, 1921. Prof. Maurice Lugeon, Lausanne. 1921. Prof. Hans Schardt, Zürich. 1921. Dr. Jakob Johannes Sederholm, Helsingfors. 1921. Dr. Henry Stephens Washington, Washington, D.C. (U.S.A.). 1923. Prof. Lucien Cayeux, Paris. Prof. John M. Clarke, Albany, N.Y. (U.S.A.). 1923. 1923. Prof. Henri Douvillé, Paris.

Prof. Waldemar Lindgren, Boston, Mass. (U.S.A.).

LIST OF

THE FOREIGN CORRESPONDENTS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1924.

Date of Election.

- 1889. Dr. Rogier Diederik Marius Verbeek, The Hague.
- 1898. Dr. W. H. Dall, Washington, D.C. (U.S.A.).
- 1899. Dr. Gerhard Holm, Stockholm.
- 1900. Prof. Federico Sacco, Turin.
- 1902. Dr. Thorvaldr Thoroddsen, Copenhagen. (Deceased.)
- 1904. Dr. Erich Dagobert von Drygalski, Charlottenburg.
- 1904. Prof. Giuseppe de Lorenzo, Naples.
- 1904. The Hon. Frank Springer, East Las Veyas, New Mexico (U.S.A.).
- 1906. Prof. William Morris Davis, Cambridge, Mass. (U.S.A.).
- 1909. Dr. Daniel de Cortázar, Madrid.
- 1911. Prof. Arvid Gustaf Högbom, Upsala.
- 1911. Prof. Charles Depéret, Lyons.
- 1912. Dr. Whitman Cross, Washington, D.C. (U.S.A.).
- 1912. Baron Ferencz Nopesa, Vienna.
- 1912. Prof. Karl Diener, Vienna.
- 1913. Dr. Per Johan Holmquist, Stockholm.
- 1921. Dr. A. E. Maurice Cossmann, Paris. (Deceased.)
- 1921. Prof. Henry de Dorlodot, Louvain.
- 1921. Prof. Louis Duparc, Geneva.
- 1921. Prof. Johan Kiær, Oslo.
- 1921. Prof. John J. Stevenson, New York City. (Deceased.)
- 1923. Prof. Emile Argand, Neuchâtel.
- 1923. Prof. Léon William Collet, Geneva.
- 1923. Prof. Reginald Aldworth Daly, Cambridge, Mass. (U.S.A.).
- 1923. Prof. G. Delépine, Lille.
- 1923. Prof. Paul Fourmarier, Liége.
- 1923. Prof. Victor Moritz Goldschmidt, Oslo.
- 1923. Prof. Thore Gustafsson Halle, Stockholm.
- 1923. Prof. James Furman Kemp, New York City (U.S.A.).
- 1923. Prof. Carl Frederik Kolderup, Bergen.
- 1923. Prof. Carlos I. Lisson, Lima.
- 1923. Prof. Gustaaf Adolf Frederik Molengraaff, Delft.
- 1923. Dr. Armand Rénier, Brussels.
- 1923. Prof. Pierre Termier, Paris.
- 1923. Dr. Frederick Eugene Wright, Washington, D.C. (U.S.A.).

[Note.—The Lists of Awards of Medals and Funds, up to the year 1907 inclusive, are published in the 'History of the Geological Society.']

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND,'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

To promote researches concerning the mineral structure of the Earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1908. Prof. Paul von Groth.

1909. Mr. Horace B. Woodward.

1910. Prof. William B. Scott.

1911. Prof. Waldemar C. Brögger.

1912. Sir Lazarus Fletcher.

1913. The Rev. Osmond Fisher.

1914. Prof. John Edward Marr.

1915. Sir T. W. Edgeworth David.

1916. Dr. A. P. Karpinsky.

1917. Prof. A. F. A. Lacroix.

1918. Dr. Charles D. Walcott.

1919. Sir Aubrey Strahan.

1920. Prof. G. J. De Geer.

1921 Dr. B. N. Peach.

1921. Dr. John Horne. 1922. Dr. Alfred Harker.

1923. Mr. William Whitaker.

1924. Sir A. Smith Woodward.

1925. Mr. G. W. Lamplugh.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1908. Dr. Herbert Henry Thomas. 1909. Mr. Arthur J. C. Molyneux.

1910. Mr. Edward B. Bailey.

1911. Prof. Owen Thomas Jones.

1912. Mr. Charles Irving Gardiner.

1913. Mr. William Wickham King.

1914. Mr. R. Bullen Newton.

1915. Mr. Charles Bertie Wedd.

1916. Mr. William Bourke Wright.

1917. Prof. Percy G. H. Boswell.

1918. Mr. Albert Ernest Kitson.

1919. Dr. A. L. Du Toit.

1920. Mr. William B. R. King.

1921. Dr. Thomas O. Bosworth.

1922. Dr. Leonard J. Wills.

1923. Mr. Harold Herbert Read.

1924. Dr. Cecil Edgar Tilley.

1925. Dr. Alfred Brammall.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, BART., F.R.S., F.G.S.

- 'To be applied in every consecutive year, in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'
- 1908. Prof. Albert Charles Seward.
- 1909. Prof. Grenville A. J. Cole.
- 1910. Prof. Arthur P. Coleman.
- 1911. Mr. Richard Hill Tiddeman.
- 1912. Prof. Louis Dollo.
- 1913. Mr. George Barrow.
- 1914. Mr. William A. E. Ussher.
- 1915. Prof. William W. Watts.
- 1916. Dr. Robert Kidston.

- 1917. Dr. George F. Matthew.
- 1918. Mr. Joseph Burr Tyrrell.
- 1919. Miss Gertrude L. Elles.
- 1920. Dame E. M. R. Shakespear.
- 1921. Mr. Edgar Sterling Cobbold.
- 1922. Dr. John William Evans.
- 1923. Prof. John Joly.
- 1924. Dr. Walcot Gibson.
- 1925. Dr. Herbert H. Thomas.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

- 1908. Miss Ethel Gertrude Skeat.
- 1909. Dr. James Vincent Elsden.
- 1910. Mr. John Walker Stather. 1911. Mr. Edgar Sterling Cobbold.
- 1912. Dr. Arthur Morley Davies.
- 1913. Mr. Ernest E. L. Dixon.
- 1914. Mr. Frederick Nairn Haward.
- 1915. Mr. David Cledlyn Evans.
- 1916. Mr. George Walter Tyrrell.

- 1917. Dr. William Mackie.
- 1918. Mr. Thomas Crook.
- 1919. Mrs. Eleanor Mary Reid.
- 1920. Dr. David Woolacott.
- 1921. Dr. Albert Gilligan.
- 1922. Dr. Herbert Bolton.
- 1923. Mr. Thomas H. Withers.
- 1924. Dr. Leonard Frank Spath.
- 1925. Dr. Arthur E. Trueman.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, BART., F.R.S., F.G.S.

The Medal 'to be cast in bronze and to be given annually ' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions, at the discretion of the Council, for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

There is a further provision for suspending the award for one year, and in such case for the awarding of a Medal to 'each of two persons who have been jointly engaged in the same exploration in the same country, or perhaps on allied subjects in different countries, the proportion of interest always not being less to each Medal than one third of the annual interest.'

1908. Mr. Richard Dixon Oldham.

1909. Prof. Percy Fry Kendall.

1910. Dr. Arthur Vaughan.

1911. Dr. Francis Arthur Bather. Dr. Arthur Walton Rowe.

1912. Mr. Philip Lake.

1913. Mr. Sydney S. Buckman.

1914. Mr. Charles S. Middlemiss.

1915. Prof. Edmund J. Garwood.

1916. Dr. Charles W. Andrews.

1917. Dr. Wheelton Hind.

1918. Mr. Henry Woods.

1919. Dr. William Fraser Hume.

1920. Dr. Edward Greenly.

1921. M. E. de Margerie.

1922. Dr. Charles Davison.

1923. M. Gustave F. Dollfus.

1924. Mr. W. Wickham King. 1925. Mr. John F. N. Green.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

- 1908. Prof. T. Franklin Sibly.
- 1908. Mr. H. J. Osborne White.
- 1909. Mr. H. Brantwood Maufe.
- 1909. Mr. Robert G. Carruthers.
- 1910. Dr. F. R. Cowper Reed.
- 1910. Dr. Robert Broom.
- 1911. Prof. Charles Gilbert Cullis.
- 1912. Dr. Arthur R. Dwerryhouse.
- 1912. Dr. Robert Heron Rastall.
- 1913. Mr. Llewellyn Treacher.
- 1914. The Rev. Walter Howchin.
- 1914. Mr. John Postlethwaite.
- 1915. Mr. John Parkinson.
- 1915. Dr. Lewis Moysey.
- 1916. Mr. Martin A. C. Hinton.
- 1916. Mr. Alfred S. Kennard.
- 1917. Prof. A. Hubert Cox.
- 1917. Mr. Tressilian C. Nicholas.

- 1918. Mr. Vincent Charles Illing.
- 1918. Mr. William Kingdon Spencer.
- 1919. Mr. John Pringle.
- 1919. Dr. Stanley Smith.
- 1920. Dr. John D. Falconer.
- 1920. Mr. Ernest S. Pinfold.
- 1921. Prof. H. L. Hawkins.
- 1921. Mr. C. E. N. Bromehead.
- 1922. Mr. Arthur Macconochie.
- 1922. Mr. David Tait.
- 1923. Prof. W. N. Benson.
- 1923. Prof. W. T. Gordon.
- 1924. Mr. John W. Tutcher.
- 1924. Mr. H. Hamshaw Thomas.
- 1925. Dr. W. Alfred Richardson.
- 1925. Dr. J. Allan Thomson.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgment of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1909. Dr. John Smith Flett. 1911. Prof. Othenio Abel.

1913. Sir Thomas H. Holland.

1915. Sir Henry Hubert Hayden. 1925. Mr. Cyril W. Knight.

1919. Sir Douglas Mawson.

, 1921. Dr. Lewis L. Fermor.

1923. Mr. E. B. Bailey.

1917. Mr. Robert G. Carruthers.

AWARDS OF THE PRESTWICH MEDAL,

ESTABLISHED UNDER THE WILL OF THE LATE

SIR JOSEPH PRESTWICH, F.R.S., F.G.S.

To apply the accumulated annual proceeds . . . at the end of every three years, in providing a Gold Medal of the value of Twenty Pounds, which, with the remainder of the proceeds, is to be awarded . . . to the person or persons, either male or female, and either resident in England or abroad, who shall have done well for the advancement of the science of Geology; or, from time to time to accumulate the annual proceeds for a period not exceeding six years, and apply the said accumulated annual proceeds to some object of special research bearing on Stratigraphical or Physical Geology, to be carried out by one single individual or by a Committee; or, failing these objects, to accumulate the annual proceeds for either three or six years, and devote such proceeds to such special purposes as may be decided.'

1909. Lady (John) Evans.

1912. Library extension.

1915. Prof. Émile Cartailhac.

1918. Sir William Boyd Dawkins.

1921. List of Geological Literature.

1924. List of Geological Literature.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND.

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1908. 'Grey-Wether' sarsens on | 1915. Mr. Joseph G. Hamling. Marlborough Downs.

1911. Mr. John Frederick Norman 1921. List of Geological Litera-Green.

1913. Mr. Bernard Smith. Mr. John Brooke Scrivenor.

1917. Mr. Henry Dewey.

1924. Publications (including List of Geological Literature).

AWARDS OF THE PROCEEDS OF THE 'DANIEL-PIDGEON FUND,'

FOUNDED BY MRS. PIDGEON, IN ACCORDANCE WITH THE WILL OF THE LATE

DANIEL PIDGEON, F.G.S.

'An annual grant derivable from the interest on the Fund, to be used at the discretion of the Council, in whatever way may in their opinion best promote Geological Original Research, their Grantees being in all cases not more than twenty-eight years of age.'

1908. Dr. James A. Douglas.

1909. Dr. Alexander M. Finlayson.

1910. Mr. Robert Boyle.

1911. Mr. Tressilian C. Nicholas.

1912. Mr. Otway H. Little.

1913. Mr. Roderick U. Sayce.

1914. Prof. Percy G. H. Boswell.

1915. Mr. E. Talbot Paris.

1916. Prof. John K. Charlesworth.

1917. Dr. Arthur Holmes.

1918. Mr. James A. Butterfield.

1920. Miss M. E. J. Chandler.

1920. Prof. L. Dudley Stamp.

1921. Mr. Ralph W. Segnit.

1921. Dr. Frederick S. Wallis.

1922. Mr. H. Price Lewis.

1923. Mr. Howel Williams.

1924. Dr. K. S. Sandford.

VOL. LXXXI.

Estimates for

INCOME EXPECTED.

INCOME EXPECTED						
	£	8.	đ.	£	8.	d.
Compositions	52	10	0			
Admission-Fees, 1925	315	0	0	367	10	0
Arrears of Annual Contributions	120	0	0	00,		Ü
Annual Contributions, 1925	2350	0	0			
Annual Contributions in advance	60	0	0	2530	0	0
Quarterly Journal Subscriptions	270	0	0	2000	Ŭ	
List of Geol. Lit. Subscriptions	30	0	0	300	0	0
Sale of the Quarterly Journal, including Long-				500	U	U
mans' Account				250	0	0
Sale of other Publications				20	0	0
Miscellaneous Receipts			*	40	0	0
Interest on Deposit-Account				10	0	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £2540 Southern Railway 5 per cent. Preference Stock		0	0			
Dividends on £3545 London, Midland, & Scottish 4 per cent. Preference Stock	141	16	0			
Dividends on £267 6s.7d. Natal 3 per cent. Stock.	8	0	4			
				351	16	4
Income of the Sorby and Hudleston Bequests .				70	0	0
				£3939	6	4

Balance in hand on January 1st, 1925 50 1 8

£3989 8 0

the Year 1925.

EXPENDITURE ESTIMATED.

Repairs and Maintenance Fund		s.		£ 200	s. 0	$\frac{d}{0}$
teopenis and identification in the contraction in t						
House-Expenditure:						
Taxes and Insurance	25	0	0			
Electric Lighting	50	0	()			
Gas	25	0	0			
Fuel	55	0	0			
Annual Cleaning	20	0	0			
Washing and Sundry Expenses	60	0	0			
Tea at Meetings	35	0	0			
	_			270	0	0
Salaries and Wages, etc				1445	0	0
Office-Expenditure:	۲0	0	0			
Stationery	100	0	0			
Miscellaneous Printing	100	0	0			
Postages and Sundry Expenses	100	0	0	050	0	0
	_			250	()	0
Library				200	0	0
Hiorary						
Publications:						
Quarterly Journal (Vol. lxxxi)	1200	0	0			
Postage on Journal, Addressing, etc.	40	0	0			
Abstracts of Proceedings, including Postage.	200	0	0			
List of Geological Literature for 1924	150	0	0			
DIST OF GOODSTONE PROPERTY.	_			1590	0	0
				£3955	0	0
	-					
Estimated Balance at December 31st, 1925				34	8	0

£3989 8 0

ROBERTIS. HERRIES, Treasurer.

Income and Expenditure during the RECEIPTS.

m (C	£	8,	d.	£ 87	<i>s</i> 10	d.
To Compositions				01	10	U
,, Admission-Fees: Arrears Current	63 264	$0 \\ 12$	0			
-				327	12	0
" Arrears of Annual Contributions				119	14	0
" Annual Contributions for 19242	2399	15	6			
" Annual Contributions in advance	80	2	0	2479	17	6
" Quarterly Journal Subscriptions	289	5	0	2T/U	11	U
" List of Geol. Lit. Subscriptions	28	16	6		_	
- To 11' ''			_	318	1	6
,, Publications: Sale of Quarterly Journal:						
, Vols. i to lxxix (less Commission £37 2s. 5d.),	244	11	7			
£7 2s. 7d.)	41	2	0			
" Other Publications	57	7	10	343	1	5
" Miscellaneous Receipts				42	10	11
" Interest on Deposit"				12	5	5
" Donation				10	0	0
" Dividends, as received:—						
£2500 India 3 per cent. Stock £2540 Southern Railway 5 per cent. Pre-	75	0	0			
ference Stock	98	8	6			
£3545 London, Midland, & Scottish Railway 4 per cent. Preference Stock	109	17	10			
£267 6s. 7d. Natal 3 per cent. Stock	6	4	4	000	7.0	_
T				289	10	8
,, Income-Tax recovered				63	19	2
,, Transfer from the Sorby & Hudleston				70	0	0
,, ,, the Prestwich Fund				63	0	0
" " ,, the Barlow-Jameson Fu	nd .	5		43	1	9

Year ended December 31st, 1924.

PAYMENTS.

		£		d.	£	8.	d.
$\mathbf{B}\mathbf{y}$	Deficit at January 1st, 1924						L1
22	Maintenance Fund				200	0	0
22	House-Expenditure:						
• • •	Taxes		8	9			
	Fire- and other Insurance	22		6			
	Electric Lighting		15	5			
	Gas		13	9			
	Fuel	67	6	0			
	Furniture and Repairs		10	3			
	Annual Cleaning	7	14	6			
	Washing and Sundry Expenses	49	9	6			
	Tea at Meetings	44	J	U	250	18	5
					200	10	0
,,	Salaries and Wages, etc.:	~~~	_				
	Permanent Secretary	550	0	0			
	Librarian	350	0	0			
	Assistant	145	15	0			
	Junior Assistant	106	15 17	6			
	House-Porter and Wife	$\frac{140}{74}$	5	0			
	Housemaid	29	3	6			
	Charwoman and Occasional Assistance	10		0			
	Accountants' Fee		16	6			
	Porter's Uniform			_	1414	2	6
	0.00 73 111					_	
99	Office-Expenditure:	41	9	1			
	Stationery	41 89	3 1	4			
	Miscellaneous Printing			0			
	Postages and Sundry Expenses	56	4	6			
	List of Fellows	00			290	14	11
					200	20	
:99	Library:	4 2 4	0	11			
	Books and Binding	TOT	14				
	Card Catalogue	14	7.46	U	165	16	11
					100	10	TL
~9 9	Publications:						
	Quarterly Journal, Vol. lxxx, Paper,	1405	0	4			
		1435		4			
	Postage on Journal, Addressing, etc	$\frac{34}{228}$		3			
	Abstracts, including Postage	137		6			
	List of Geological Literature for 1923	101			1834	17	0
					1001		
D	Balance in the Bankers' hands at						
B	December 31st, 1924	30	15	3			
	December 51st, 1924	-00	10				
-9.5	Balance in Petty Cash at December	10	e	5			
	31st, 1924	19	6	0	50	1	8
	-				90	1	0
				-	0.1050		4
					£4270	4	4
				-			

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

HENRY DEWEY, HORACE W. MONCKTON, Auditors. ROBERT S. HERRIES, Treasurer.

January 28th, 1925.

Statement of Trust-Funds and Special Funds: December 31st, 1934.

FUND. TRUST ACCOUNT. & s. d.	264 7 4	FUND,' TRUST ACCOUNT. PAYMENTS. £ s. d. By Cost of Medal. 1 0 0 0 "Award to the Medallist. 10 10 0 0 "Award from the Balance of the Fund. 29 15 1 "Balance at the Bankers' at December 31st, 1924. 24 15 0	£0.6 0 1	### GICAL FUND.* TRUST ACCOUNT. #### Solution	£123 2 3	### 12 11 By Transfer to General Account ### 2 8. d. ### 37 12 11 By Transfer to General Account ### 19 ### 11 By Transfer to Bankers' at December 31st, 1924 8 13 9 ### 11 8 ### 11 8 ### 11 8 ### 11 8 ### 11 8 ### 11 8 ### 11 8 ### 11 8 ### 11 8 ### 11 8 ### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 #### 11 8 ##### 11 8 ##### 11 8 ##### 11 8 ##### 11 8 ##### 11 8 ##### 11 8 ##### 11 8 ###### 11 8 ###### 11 8 ########	£51 15 6
To Balance at the Bankers' at January 1st, 1924 32 3 8 By Cost of Gold Medal P. Dividends on the Fund invested in £1073 Hampshire 32 3 8 M. Award from the Balance of County 3 per cent. Stock	264 7 4	To Balance at the Bankers' at January 1st, 1924 25 15 1 By Cost of Medal P., and the Bankers at January 1st, 1924 25 15 1 By Cost of Medal P., and to be mindled, & Scottish Railway 4 per cent. Debenture Stock 31 0 0 Balance at the Bankers' at 1 lncome Tax recovered	£66 0. 1	To Balance at the Bankers' at January 1st, 1924 52 15 3 By Cost of Medal To Balance at the Bankers' at January 1st, 1924 52 15 3 By Cost of Medal Metropolitan 3½ per cent. Stock	£123 2 3	To Balance at the Bankers' at January 1st, 1924 37 12 11 By Trans, Dividends (less Income-Tax) on the Fund invested in 2468 London & North-Eastern Railway 3 per cent. Debenture Stock	£51 15 6

	v 4 · · · · · · ·	101	.: 00	0	<i>₽</i> 4 ∞	01
	5 6. Co		i. d.		s. a 11 10	67
£ s. 10 12 10 12 10 12	210 12 3 5 5 (3) 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5	£72 10	£ 863 (63 15 1	£78 15	£ 30 1 46 1	£77
		13	,	£		1 25 II
### BIGSBY FUND.* TRUST ACCOUNT. ### Solution ### Solution ### A	### GEOLOGICAL RELIEF FUND. TRUST ACCOUNT. ###################################		'Prestwich Trust Fund.' Trust Account. 2 s. d. 1924 57 15 0 By Transfer to General Account Balance at the Bankers' at December 31st, 1924 21 0 0	·	**Daniel-Pidgeon Fund.** Trust Account. 2	
8. d. 6 8 17 8 4 8 4	8 H 3 7 4	0 6	sr Fu s. d. 15 0 0 0	0	8. a. 8. 8. 111 4 111 4 5 0	2 0
% 8. 8. 17 4 17 8 17 8 17	RELIEF £ 8. 67 7	1 0 0 £72 10 9	RUST £ 8. 57 15 21 0	£78 15	30 11 8 15 15 11 8 11 15 15 11 15 15 11 15	222
To Balance at the Bankers' at January 1st, 1924 4 """ """ """ """ """ """ """ """ """	RECEIPTS. thers' at January 1s Fund invested in £	s per cent, Stock , Interest on Deposit	'Prestwich Transaction Balance at the Bankers' at Janúary 1st, 1924 5' 'Dividends on the Fund invested in £700 India 3 per cent. Stock	£73	RECEIPTS. To Balance at the Bankers' at January 1st, 1924 Dividends on the Fund invested in £1019 1s. 2d. Bristol Corporation 3 per cent. Stock	

NT.	
RUST ACCOU	
H	
FUND.	
RESEARCH]	
\simeq	
COLOGICAL	
UTD(
\bigcirc	
UTDOOR GE	

£ 8, d, 15 0 0 109 3 10	£124 3 10	£ 8, d, 70 0 0	0 0 023	£ % d. 11 9 5 3 9 7	£514 19 0	ত ন ন	£395 5 2
By Grant to the Hull Geological Society	313		137	CE FUND. PAYMENTS. By Payments during the year	£61	LICATION FUND. By Balance at the Bankers' at December 31st, 1924 £39	360
## Receptors. To Balance at the Bankers' at January 1st, 1924 65 10 2 "Dividend (less Income-Tax) on the Fund invested in ## ## ## ## ## ## ## ## ## ## ## ## ##	£124 3 10	SORBY AND HUDLESTON BEQUESTS. (£1000 Stock each.) RECEIPTS. # s. d. PAYMENTS. \$2000 Canada 3½ per cent. Stock	0 0 023	To Balance at the Bankers at January 1st, 1924 281 1 3 By Payments during the year	£514 19 0	VOLUNTARY PUBLICATION FUND. To Balance at the Bankers' on January 1st, 1924 £229 17 10 By Balance at the Bankers' at December 31st, 1924 £395 5, Donations and Subscriptions	£395 5 2

We have compared this Statement with the Books and Accounts presented to us, and find them to agree. ROBERT S. HERRIES, Treasurer.

January 28th, 1925.

HENRY DEWEY, HORACE W. MONCKTON, Auditors.

Statement relating to the Society's Property. December 31st, 1924.

Delanes in the Paulsans' hands December 21st	£	8.	đ.	£	s	d,
Balance in the Bankers' hands, December 31st, 1924	30	15	3			
Balance in Petty Cash, December 31st, 1924	19	6	5	~0	7	0
Balance of the Voluntary Publication Fund				50 395	1 5	8 2
Balance of the Maintenance Fund				393	9	7
Arrears of Annual Contributions				201	12	0
				£1040	8	5
Funded Property:—	Cost	Pri	ce.	Value Dec. 31st		
£2500 India 3 per cent. Stock	2623	19	0	1425	0	0
£2540 Southern Railway 5 per cent. Preference Stock	4110	2	9	2590	16	0
£3545 London, Midland, & Scottish Railway 4 per cent. Preference Stock	4749	10	0	2906	18	0
£267 6s. 7d. Natal 3 per cent. Stock	250	0	0	195	2	11
£2000 Canada $3\frac{1}{2}$ per cent. Stock [1930–1950] (Sorby and Hudleston Bequests)	1982	11	0	1620	0	0
\mathfrak{L}	13,716	3 2	9	£8737	16	11

[Note.—The above amount does not include the value of the Library, Furniture, and Stock of unsold Publications.]

ROBERT S. HERRIES, Treasurer.

January 28th, 1925.

AWARD OF THE WOLLASTON MEDAL.

In presenting the Wollaston Medal to George William Lamplugh, F.R.S., the President addressed him as follows:—

Mr. Lamplugh,-

It is with the greatest pleasure—a pleasure which is, I am sure, shared by the Fellows generally—that I hand to you the Wollaston Medal, the highest honour that it is in the power of the Society to award. When you received the Bigsby Medal in 1901, you were already widely known by your work on the Cretaceous rocks and the Glacial deposits of the North of England. Your work on the Isle of Man was then on the eve of publication: it proved to be a mine of original observations on glacial phenomena and rock-structures, especially crush-conglomerates. You have since added still further to our knowledge of the Mesozoic formations, and have assisted, in no small measure, in the just interpretation of the evidences of glacial action in this country. In a widely different sphere you have studied the erosion of the Batoka Gorge of the Zambezi, and there are innumerable other problems of Stratigraphical and Dynamical Geology that you have illuminated in the course of your long and varied experience as a member of the Geological Survey. But, perhaps, your most original contribution to our science was the enunciation, in your Presidential Address of 1919, of the important principle that the present outcrops of formations coincide more or less closely with the tracts in which they attained their greatest original thickness.

Mr. LAMPLUGH replied in the following words:-

Mr. President,—

I am proud indeed to be admitted to the rank of the Wollaston Medallists, and I ask you, Sir, to convey my thanks to the Council for this treasured distinction.

On the previous occasion to which you have referred, the Council awarded to me an honour which was partly anticipatory in its terms, and was handed to me by the President with an expression of trust. Conscious as I now am how far below intention my achievement has been and must be, it is with the deepest gratification that I receive this Medal as a token that the Council has

taken a favourable view of the work done, as well as of the intention.

May I also thank you, Sir, personally, for your appreciation of my work?

AWARD OF THE MURCHISON MEDAL.

The PRESIDENT then presented the Murchison Medal to Dr. HERBERT HENRY THOMAS, M.A., addressing him as follows :--

Dr. THOMAS,-

It is difficult to summarize in a few words your services to our Science, for which I now hand to you the Murchison Medal. Your most striking contributions have been to our knowledge of the mineral contents of sedimentary rocks, which have yielded valuable information concerning their origin. As Petrographer to the Geological Survey, you have contributed again and again to the successful issue of its labours. I should like to stress, more especially, your work on the igneous and the sedimentary rocks of South Wales, and that on the Tertiary minor intrusions of the Island of Mull. Nor should we forget the interesting memoir in which you traced the origin of the extraneous rocks of Stonehenge to the hills of Pembrokeshire. I must not conclude without a reference to the great debt which the Society owes to you, for your untiring devotion to its interests during your long term of office as its Secretary.

Dr. Thomas replied in the following words:-

Mr. President,-

I am deeply sensible of the great honour that the Council of the Society has conferred upon me in awarding to me the Murchison Medal, and in thus adding my name to a list so long and of recipients so worthy.

For me, as a geologist with wide sympathies, and more particularly as a petrologist, it greatly enhances my gratification to receive the Medal at your hands, and I thank you personally for the graceful

words with which you have accompanied the award.

To every right-minded man, expressions and tokens of approval

are extremely precious; but it is on occasions such as these that he realizes how great is his debt to his friends and colleagues, and how little his position is due to his own inherent qualities or effort.

To my dear friend and teacher, Prof. Marr, I owe more than mere words can express; and in the same connexion I should be ungrateful if I failed to acknowledge the great educational benefits that I received by working in close co-operation with Prof. Sollas during the three years that I was privileged to act as his assistant at Oxford, a period to which I may refer as my 'geological adolescence'.

The honour that the Council has conferred upon me will stimulate me, if incentive be needed, to further endeavour in the cause of our Science, and I trust that I may never fail to mete out to others such kindly help and encouragement as it has ever been my own good fortune to receive.

AWARD OF THE LYELL MEDAL.

In presenting the Lyell Medal to John Frederick Norman Green, B.A., the President addressed him as follows:—

Mr. Green,—

In awarding to you the Lyell Medal, the Council recognizes you as a worthy representative of the great succession of non-professional geologists who have done so much for the science in this country. In your work on the ancient rocks of St. David's you were able to present a clear interpretation of a much-debated area. This was followed by no less important investigations in the Lake District, while your recent contributions to the difficult problems presented by the Pre-Cambrian rocks of the West of Scotland are fresh in the memory of us all. As an official of one of our great Government Departments, you have, I need not say, always borne in mind the value of scientific research in promoting the well-being of all classes.

Mr. Green replied in the following words:-

Mr. President,—

It has been more by luck than purpose that my researches have

led me among the most beautiful scenes of our lovely country. But if, in the course of these happy wanderings, while striving to learn something of the architecture of the hills, I have been so fortunate as to add a stone to the noble building of British Geology, it has been due to the kindly advice and assistance of my professional friends, particularly Mr. George Barrow, by whose encouragement I was brought to attempt geological work. It gives me great pleasure to know that Prof. Marr, to whose teaching I owe so much, was himself a recipient of the Lyell Medal; and also to take it from the hands of one with whom I have often been associated in promoting investigation of the remoter lands of the Empire.

AWARD OF THE BIGSBY MEDAL.

The PRESIDENT then handed the Bigsby Medal, awarded to CYRIL WORKMAN KNIGHT, to Mr. LUCIEN PACAUD, Permanent Secretary, Canadian High Commissioner's Office, for transmission to the recipient, addressing him as follows:—

Mr. PACAUD,-

It is with the greatest pleasure that the Council of the Geological Society has awarded the Bigsby Medal, founded by Dr. J. J. Bigsby, a distinguished Canadian geologist, to Mr. Cyril W.

Knight.

It is impossible within the limits of time available to me on this occasion to enumerate all the claims that Mr. Knight possesses to our recognition. In co-operation with Prof. William Campbell, he developed the study of ores by the examination of polished surfaces. In the Pre-Cambrian rocks of South-Eastern Ontario he was able to demonstrate that the Hastings Series lies unconformably on the Grenville, a question which has been in dispute since the time of Logan. His work on the underground geology of the Sudbury and Cobalt areas was a worthy sequel to that of Dr. Miller, who it was that, a few days before his death, did a last service to this Society in supplying us with particulars of Mr. Knight's achievements.

In awarding this Medal to Mr. Knight, the Council takes the opportunity of recognizing the splendid contributions to Geological

Science made by our Canadian comrades.

Mr. PACAUD replied in the following words:-

Mr. President,—

May I be permitted, as my first word, to convey to you the Canadian High Commissioner's deep regret at being unable to accept, owing to a previous engagement, your most kind invitation?

Mr. Larkin has asked me to represent him to-day, and in the fulfilment of this very pleasant mission, I feel that no word of mine could better express the thoughts and feelings of Mr. Knight, than to hasten to offer to you on his behalf his warmest thanks for the high honour which you have so kindly bestowed upon him on this occasion.

In awarding to Mr. Knight the Bigsby Medal, founded by a distinguished Canadian, you have shown your appreciation of his valuable contributions to geological research, and I know that I am interpreting the feelings of all Canadians in assuring you that they will all share in this well-merited recognition which has thus crowned the efforts of their eminent fellow-countryman.

In forwarding this Medal to Mr. Knight, I will not fail to let him know the kind words that you have uttered, Sir, words which I know will be received by him with pride and with gratitude.

AWARD FROM THE WOLLASTON DONATION FUND.

In presenting the Balance of the Proceeds of the Wollaston Donation Fund to Dr. Alfred Brammall, the President addressed him as follows:—

Dr. Brammall,-

In awarding to you the Balance of the Proceeds of the Wollaston Fund, the Council has recognized with pleasure your careful and original investigations on the processes of metamorphism. You have also investigated the constitution and structure of the granites of Dartmoor, and thrown fresh light on the successive intrusions that have taken place, and the characters that distinguish them one from the other, as well as on the subsequent earth-movements to which they bear witness. The Council looks forward to a future as fruitful in contributions from you to Geological Science as the past has been.

AWARD FROM THE MURCHISON GEOLOGICAL FUND.

The PRESIDENT then presented the Balance of the Proceeds of the Murchison Geological Fund to Dr. Arthur Elijan Trueman, addressing him as follows:—

Dr. TRUEMAN,-

Palæontology, for its best expression, must not only be brought into relation with the problems of Neontology, but must itself lead the way towards solving those philosophical questions which the study of fossils is most likely to answer. Your published work shows that you have consistently kept in mind this aspect of Palæontology, whether in tracing the ontogeny or phylogeny of Lias Ammonites, the sequence of Lamellibranchs in consecutive horizons of the Coal Measures, the relationships of Lias Gastropods, or the percentages of growth-shapes in Gryphæa. The same trend of mind has led you to the discussion of such different subjects as zonal nomenclature and the biological concept of species. Your investigations into Ammonite palæontology have enabled you not only to elucidate in great detail the Lias of Lincolnshire and Glamorgan, and to make a zonal map of the coast-line near Cardiff, but also to test in your practice the theories held by workers on the Lias in other districts. As a teacher, you have considered the advanced student by demonstrating new methods for studying the morphology of the Ammonite septum, and remembered the needs of the young amateur by giving him an elementary text-book. Further work by you on the Lias, especially work dealing with Ammonites and their evolution, is eagerly awaited.

AWARDS FROM THE LYELL GEOLOGICAL FUND.

In handing a moiety of the Balance of the Proceeds of the Lyell Geological Fund, awarded to Dr. James Allan Thomson, to Dr. J. S. Flett for transmission to the recipient, the President addressed him in the following words:—

Dr. FLETT,-

I have much pleasure in handing to you a Moiety of the Balance of the Proceeds of the Lyell Fund awarded to Dr. James Allan Thomson, who has made important contributions to more than one department of Geological Science. His most extensive studies have been in the Palæontology of New Zealand, and in this connexion he has devoted his chief attention to the Brachiopods. He has also published valuable papers on petrological and economic subjects, especially in relation to New Zealand and Western Australia.

The President then handed the other moiety of the Balance of the Proceeds of the Lyell Geological Fund, awarded to Dr. William Alfred Richardson, to Mr. W. Campbell Smith for transmission to the recipient, addressing him as follows:—

Mr. Campbell Smith,-

Although Dr. Richardson is by profession a civil engineer, he has made substantial contributions to Geological Science, which constitute ample justification for the award to him of a Moiety of the Balance of the Proceeds of the Lyell Geological Fund. His work on the origin and mode of occurrence of concretionary rocks has gained wide recognition. Of still greater importance has been his examination of the relative frequency of occurrence of different types of igneous rocks, the results of which afford undeniable support to those who believe in a fundamental differentiation into basic and acid magmas, followed by a further segregation into different types.

VOL. LXXXI.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT. DR. J. W. EVANS, C.B.E., F.R.S.

The Geological Society has lost in the past year some of its most eminent Fellows and Foreign Correspondents.

The death at Enghien, near Paris, of ALEXANDRE EDOUARD MAURICE COSSMANN, on May 17th, 1924, in his 74th year, removes the name of a distinguished palæontologist from our list of Foreign Correspondents. He was born in Paris on October 18th, 1850, and at an early age entered l'École Centrale of Paris as an engineering student, from which, after a successful training, he received an appointment on the staff of the Chemin de Fer du Nord, finally becoming Chief Technical Officer of that railway, a position which he held for a great part of his life. Evidently, his engineering duties must have opened up to him many opportunities for visiting sections and quarries in the neighbourhood of Paris, thus enabling him to obtain important collections of fossils representative of the older Tertiary faunas of that region. The study of such material, especially its molluscan part, led him to publish valuable observations, his first paper being issued in the 'Journal de Conchyliologie' during the year 1879, on some new Gastropods from the Oligocene deposits of Étampes, near Paris. From that time until the period of his last illness a considerable flow of literature emanated from his pen, so much so that it may reasonably be stated that Cossmann came to be one of the most prolific writers among his contemporaries on subjects dealing with the science of Palæoconchology. It is only possible, however, in the present brief notice, to refer to a few of his more important memoirs. His first great work, under the title of 'Catalogue illustré des Coquilles de l'Eocène des Environs de Paris', was published by the Royal Malacological Society of Belgium, in a number of fascicules and appendices, between 1886 and 1913. It comprised a revision of some 3000 species of Mollusca, originally described by Deshayes in those well-known classical volumes of that author, issued between the years 1824 and 1866, besides including the treatment of many new genera and species. A serious defect of this work was, however, Cossmann's adoption of pre-Linnean generic names, a procedure which he later condemned, in favour of a nomenclature dating from the 10th edition of Linnæus's 'Systema Naturae' 1758, now

universally recognized. Another of his larger memoirs, and one which forcibly exhibits considerable powers of research and observations, was the 'Essais de Paléoconchologie Comparée', of which twelve Livraisons were published between 1895 and 1916, the 13th Livraison, not quite completed, being promised for issue at an early date under the capable editorship of his friend, Gustave Dollfus. This work analytically discusses the merits and characters of Gastropod genera, each genus being followed by a list of species arranged in stratigraphical sequence, thus displaying its distribution through older geological seas to those of the present day. Then again, I must not forget to mention the 'Iconographie complète des Coquilles Fossiles de l'Eocène du Bassin de Paris', which was prepared in conjunction with G. Pissarro, and issued in large quarto parts between 1904 and 1913, containing hundreds of excellent figures of the whole of the Paris Basin Eocene Mollusca with their geological horizons and This work will be long recognized as a standard reference-guide for all students of that fauna. Several memoirs were written on the Miocene Mollusca of European and other countries, although those from the Aquitanian area of France are perhaps best known. Besides his contributions to literature on Tertiary shells, Cossmann added much to our knowledge of Mesozoic forms from France and other countries, ranging from the Lias to the Upper Cretaceous, while an excellent memoir entitled 'Sur l'Évolution des Trigonies' was published in 1912. He, moreover, made himself acquainted with the palæoconchology of distant regions, and issued writings on material sent to him for investigation from India, Egypt, the United States, Panama, Martinique, and the Argentine Republic. He established the well-known 'Revue Critique de Paléozoologie' in 1897, becoming its Director in due course, he himself furnishing analyses of all the conchological literature from its foundation almost up to the moment of his last illness; it was issued in quarterly parts, and at the present time has reached its 28th year of publication. is stated that this 'Revue' is to be continued under the superintendence of M. G. Dollfus.

It is interesting to note that the Gastropod genera Cossmannia (R. B. Newton, 1891), Cossmannella (Mayer-Eymar, 1897), and Cossmannica (Dall & Bartsch, 1904) were founded in honour of M. Cossmann, his name having been also utilized for many specific determinations in connexion with Molluscan terminology.

On account of his great scientific attainments in furtherance of palæoconchology, Cossmann received some well-merited distinctions from his own and other countries. France appointed him a Chevalier of the Legion of Honour, and Belgium a Chevalier of the Order of Leopold. He had, also, held the Presidency of the Geological Society of France (1915), and was besides a Member of the Linnean Society of Bordeaux, and one of the original members of the Malacological Society of London; while another connexion which he treasured most highly was his election in 1921 as a Foreign Correspondent of the Geological Society of London. He has left his collections of fossils to the Sorbonne in Paris, and his library to the Geological Society of France. [R. B. N.]

John James Stevenson, Professor Emeritus of Geology in New York University, was one of the most distinguished Foreign Correspondents of this Society. He was born in New York on October 10th, 1841, graduated at the University of the City of New York in 1863, and four years later, after obtaining his doctorate, he took charge of mining work in Nevada. In 1869 he accepted the Professorship of Chemistry & Natural History at the University of West Virginia, and in 1871 returned to the University of New York as Professor of Geology, a post which he held for 38 years, becoming Professor Emeritus in 1909. He was President of the New York Academy of Sciences from 1896 to 1898, and President in 1899 of the Geological Society of America, of which Society he was an original member and its first organizing secretary.

Stevenson was the last surviving geologist of the United States Geological Survey West of the 100th Meridian, known as the 'Wheeler Survey'. The greater part of his work on this Survey was done in Colorado and New Mexico, at a time when most of the exploration had to be carried out under the protection of a military escort, and attacks from Indians were a constant menace. His reports on these States were published in 1875 and 1881, and his general conclusions on their stratigraphy have stood the test of later work by geologists for nearly half a century. In addition to this survey work in the West, Stevenson served for three summers on the Ohio Geological Survey, and, later, on the Pennsylvania Geological Survey, to which he contributed three memoirs between 1876 and 1888. He devoted a great deal of attention to the coal-

bearing formations, and became the leading American authority on coal and the stratigraphy of the Carboniferous System. For a geologist of very wide experience he published rarely, and it is a subject of great regret that his monographic work on the 'Formation of Coal-Beds' was published in 1913, when only half completed, owing to failing eyesight which prohibited all reading for the last years of his life. He died at the age of 82, on August 10th, 1924. He had been elected a Foreign Correspondent of this Society in 1921. [W. C. S.]

Dr. THORVALDR THORODDSEN, who died on September 28th, 1921, in his 67th year, was a man of one subject; but that subject was his native country, Iceland, and he studied it in all its aspectsbibliographic, historic, literary, ethnological, economic, meteorological, botanical, and zoological. It is as a geologist, however, that we here can best appreciate his untiring labours. When Thoroddsen began his journeys in 1881, thanks to the remoteness and extent of the country—in size and shape much the same as Ireland—and to the difficulties, not to say dangers, of travel through its inhospitable wastes, the geology of Iceland as a whole was, he claimed, scarcely known. 'Of its 130 volcanoes, only three or four were at all familiar, and of its numerous Jökuls (or glacier-mountains) not one had been studied scientifically'. He recognized the obstacles in his path: the uniformity in the mass of the older rocks, coupled with their infinite variety of minor detail, and the rarity of fossiliferous formations. Thoroddsen had to make his own topographic maps, and to measure some 1200 heights; but in 1901 he produced his well-known geological map on a scale of 1:600,000, and in 'Petermann's Mittheilungen' for 1905-1906 he summed up his results in his memoir: 'Island, Grundriss der Geographie & Geologie'. This is no mere piece of description, but a logically argued account of the changes undergone by Iceland in geological time. It would hardly be possible to mention here the numerous problems therein discussed and illuminated, if not always solved. The value of his work has long been recognized: in 1902 he was made a titular professor of Copenhagen University, and elected a Foreign Correspondent of our Society. His name will be held in honour by every Icelander, and in the world outside by every geologist. [F. A. B.]

By the death of Sir Archibald Geikie on November 10th, 1924, British geology has lost its leader, and the Geological

Society its most eminent Fellow. From an early age to the end of his long life he made the interests of the Society one of his first cares. Elected a Fellow in 1859, he served on the Council in 1883, and for many subsequent years. He was a Vice-President in 1886–88 and President in 1890–92. On the occasion of the Centenary of the Society in 1907, he acceded to a generally expressed desire that he should preside for a second term (1906–08), and on relinquishing the Chair was elected Foreign Secretary. For many years he had been constant in his attendance at the Meetings, and when advancing years rendered this impossible, he tendered his resignation; but, at the unanimous request of the Council, he continued to perform the duties of the post to the end of his life.

He was born in Edinburgh on December 28th, 1835. For the details of his early life we are indebted to his autobiography, 'A Long Life's Work'. This volume, which was published only a few months before his death, shows no signs of waning powers or of failing memory. In it he describes the innumerable functions in which he took a leading part, the appointments which he held, his travels, and some of the many honours that he received. He dwells, too, on the friends whom he made and on the encouragement which he received from them as a young man and in afterlife; but more especially interesting to us is the revelation of the inner thoughts of a boy who, in obedience to a natural bent and rather to the alarm of his father, made geology the occupation of his life, and eventually attained the highest posts open to a man of science in this country.

A dormant love of geology was roused accidentally soon after he left school. The finding of a fossil plant in a block of limestone in Burdiehouse Quarry set his active mind speculating on the relies of past ages that were entombed in the crust of the Earth, and from that moment the rocks and their fossils became increasingly the subject of his thoughts. He made the acquaintance of Robert Chambers, afterwards known to be the author of the 'Vestiges of Creation', and of other geologists, and read every book on geology that he could lay hands on, deriving, however, a greater stimulus from the enthusiasm and literary charm of Hugh Miller's 'Old Red Sandstone' than from some more informing works. But, more than by any book, he was inspired by his own study of the rocks near Edinburgh, with their abundance of fossils and of evidence of ancient volcanic outbursts.

Though the boy's bent was clearly indicated, his father found it difficult to believe that a study of geology could provide a livelihood. He arranged, therefore, that young Geikie should become a banker, after a preliminary training for two years in a lawyer's office. The interruption was brief, for the boy's heart was among the hills of Midlothian and far from the office. He was out in the field again long before the two years had elapsed. Determined, however, to pursue literary studies in addition to science, he matriculated at Edinburgh University in 1854 as a student of Humanity (that is, Latin), and although domestic circumstances prevented him from completing the course, he gained the reputation of being one of the best classical scholars of his year and the best writer of English prose among his class-fellows. The literary ability thus shown proved to be one of the principal factors in his success in after-life.

In the meantime Geikie had been prosecuting geological work in Skye with such success that he impressed the geologists of the day as a young man of unusual promise. When, therefore, recruits were enquired for by Sir Roderick Murchison, then Director-General of the Geological Survey, he was warmly recommended by Hugh Miller. A walk over Arthur's Seat with Ramsay, at that time Local Director, took the place of the examination of later days, and the appointment was made in 1855. After a year's training in the field with Ramsay, the young geologist was regarded as competent, and was set to work in the surroundings of Edinburgh. He found time, nevertheless, to complete his work in Skye, and to write an account of it, which was communicated to this Society in 1857.

This period he found to be the most studious of his life; but, however great might be the calls upon his endurance, he never failed to make time for companionship with the classical authors and with the best English writers from Chaucer to our own day. The spirit with which he was imbued in his field-work is best expressed in his own words: 'The work on which I was now engaged, and to which I had dedicated my life, was not merely an industrial employment; the means of getting a livelihood; a pleasant occupation for mind and body. It often wore to me an aspect infinitely higher and nobler. It was in reality a methodical study of the works of the Creator of the Universe, a deciphering of His legibly-written record of some of the stages through which this part of our planet passed in His hands before it was shaped

into its present form' ('A Long Life's Work', pp. 55, 56). The deep joy that he felt in the study of Nature had to be shared with others, and in 1858 he produced a little book, 'The Story of a Boulder', the first of a long series by which he carried his message to all parts of the civilized world.

In 1860 it fell to Geikie to complete the 'Life of Edward Forbes', which had been left unfinished through the death of Prof. George Wilson. Some of Forbes's relations hesitated before entrusting the task to so young a man, but the book, when published in 1861, showed that the confidence felt in him had not been misplaced. This was the first of several biographies in which Geikie, with many a kindly touch, recorded the personalities and achievements of friends who had gone before him. It was followed in 1869 by the life of James David Forbes, in 1875 by that of Murchison, and in 1895 by that of Ramsay. In all of them his close touch with current geological research and his sound judgment enabled him to present a true estimate of the progress in science due to each of these distinguished men.

In 1871 the Natural History Professorship at Edinburgh University was divided into two, and Geology with Mineralogy became the subjects of a new Professorship. Murchison offered to endow the new Chair, on the understanding that he should nominate the first Professor. He put forward Geikie's name, but the power to nominate was objected to by the Home Office as an infringement of the prerogative of the Crown, and the Science and Art Department considered it inadvisable that the posts of Director of the Geological Survey of Scotland and the Professorship should be held by the same man. The appointment was made nevertheless, mainly through the exertions of Lyon Playfair, at that time Member for the University. During his tenure of this post, which lasted till he was appointed Director-General of the Survey in 1882, Geikie did much to revive the renown of the old Scottish Geological School. He had at first no lectureroom to himself and no diagrams or specimens, but made use of the exceptional advantages offered by the neighbourhood of Edinburgh to conduct geological excursions, which are still gratefully remembered by his old students.

In 1860 Murchison invited Geikie to accompany him to the Highlands, with the object of following up the conclusions to be drawn from Charles Peach's discovery of Cambrian fossils in North-Western Sutherland. Writing in 1924, Geikie admits that this

expedition 'was a premature attempt the true structure of the Highlands was far too complicated to be unravelled by desultory and hasty traverses'. Neither he nor Murchison had been able to doubt the evidence of their eves that in one section after another crystalline schists overlay fossiliferous Cambrian strata with what appeared to be a natural junction. It is needless to reopen a controversy which has been laid to rest for many years, and it will suffice to say that the apparent normal superposition with its far-reaching consequences found no acceptance with Nicol, Heddle, Callaway, Bonney, and others. Geikie, partly perhaps through lovalty to his chief, for long refused to give way, and it was not till Lapworth had made his exhaustive examination of the whole Durness-Erribol region that he admitted his error. Once convinced, he hastened to correct it. He entrusted the surveying of the region to B. N. Peach and J. Horne, who with their colleagues produced what was probably the most detailed and masterly study of overthrusting on a great scale that had ever been made.

The succession of strata in the Moffat and Girvan districts was determined in somewhat similar stages. There also it had been masked by earth-movements. Faults and excessive plication had repeated the same beds over and over again, and it was only by detailed surveying and intensive study of the fossils that Lapworth unravelled the tangle. His predecessors had been content to leave as one group a series of strata varying extraordinarily in thickness and petrological character, and containing an admixture of fossils that were elsewhere characteristic of distinct formations. He reduced this enigmatical 'group' to an orderly sequence, each member of which was distinct in character and fossils, and established correlation with other parts of the kingdom. It is interesting to see how closely these Highland controversies were paralleled in the United States. There the succession of the same rocks was in question, the same difficulties in determining it were encountered, and the same mistakes were made. The 'Taconic System', founded in 1842, formed the subject of controversy for upwards of sixty vears, until it was finally proved to consist of Cambrian and Silurian strata folded and faulted together in no sort of chronological order. That the first geologists to encounter problems so calculated to deceive should have failed to master them need cause no surprise. Rather should our sympathies be extended to pioneers who were faced with the impossible task of interpreting dislocations, the existence of which could be ascertained only by prolonged and detailed mappping. But we may admit that our sympathy might have been warmer had Geikie, true lover of Nature as he was, shown more cordiality in welcoming the elucidation of the truth.

There remains, however, to his credit a great record of original unchallenged work. He made a particular study of the composition and direction of transport of the Boulder Clay, and noted the occurrence in it of stratified beds which he attributed to temporary amelioration of climate. Originally an advocate of the iceberg theory, he abandoned it in favour of Agassiz's views on ice-sheets, convinced by the work of his colleagues in Scotland and by what he saw in Northern Norway. He recognized also among the Scottish mountains the existence of moraines and glacier-borne blocks and the sites of glacial lakes as evidences of local glaciation during the last phase of the Glacial Period.

His great paper on the Old Red Sandstone of Western Europe, as a piece of masterly description, takes high rank in geological literature. His classification has in the main stood the test of time; but, with characteristic reluctance to change a view to which he had once committed himself, he persistently declined to remove the Caithness Flagstones from the Lower Old Red Sandstone, though they differed from that subdivision (as known in the Grampians) both in their fishes and in their plants. The flagstones appear in Geikie's map of Scotland as Lower Old Red, but on the Geological Survey maps as Middle Old Red Sandstone.

Volcanic episodes in the history of the Earth had engaged Geikie's attention from the first, and in 1860 he presented to the Royal Society of Edinburgh a paper on 'The Chronology of the Trap Rocks of Scotland', in which for the first time an attempt was made to arrange the volcanic periods evidenced in that country in geological sequence. In dealing with this subject he was not satisfied till he had acquired the necessary experience by visiting the volcanic regions of Auvergne, the Eifel, and Italy, and exploring the great lava-fields of Western America. In Auvergne especially, the comparatively recent features displayed by volcanic energy enabled him to picture the aspect of the ancient vents and lava-flows of the Firth of Forth. In the United States he found reason to adopt Richthofen's view that the flat beds of basalt were due to fissure-eruptions, and applied this interpretation to the Tertiary volcanic plateaux of the West Highlands. He

summed up his observations and conclusions in his standard work on the 'Ancient Volcanoes of Great Britain'.

Unlike Lyell, Geikie gained most of his experience by his own observations in the field. In addition to the work done in his leisure-time, he was for some years a member of the field-staff of the Geological Survey, and after he had attained higher posts charged mainly with administrative duties, he was constant in inspection. On these occasions his quick grasp and wide experience enabled him to give much help to his colleagues, but at the same time he made full use of the opportunities for adding to his own knowledge. Scenery from the point of view of its origin and geological significance made a strong appeal to his poetic instincts. Born, bred, and trained in Scotland, he had gazed upon many a noble landscape, and had pondered over the vast effects of denudation and the characters imposed upon the features of the country by the passage of ice-sheets. His views are embodied in 'The Scenery of Scotland', published in 1865, a book as interesting to the non-geological reader as to the expert. All his lighter books indeed, such as 'Geological Sketches at Home & Abroad' and 'Scottish Reminiscences', were written in a style to appeal to a large circle of readers.

Late in life he interested himself in the early history of geology. The Founders of Geology', first published in 1897, could only have been written by one who had a wide acquaintance with ancient and modern literature. When called upon to deliver a presidential address to the Classical Association, he chose for his subject the evidence from Latin literature of the appreciation of Nature by the Romans. Later on he further developed the theme, and visited Italy in order that he might himself study the landscapes on which the eyes of the Roman poets had dwelt.

Of all the calls made upon Geikie's untiring industry none was more severe than the production of his educational works. The 'Advanced Text-Book' is a store-house of information and a monument to the sagacity with which he handled an enormous literature. Stupendous as was the labour involved, he found the preparation of the two little primers, on Geology and Physical Geography, still more exacting—the phrasing was made the subject of many experiments on students before he could satisfy himself that he had secured the lucidity that was essential. The two small-scale geological maps, of Scotland and England respectively, prepared by him during his term of office on the

Geological Survey, are admirable examples of the pains that he took to secure clearness and what he considered to be correct versions.

As a lecturer he had many experiences, both at home and abroad, before audiences of the most varied character, including the inmates of a Deaf and Dumb Institution and the patients of the Morningside Lunatic Asylum. He was also one of that little band of distinguished men who lectured to working men in the theatre of the Jermyn Street Museum. His wide reading enabled him to choose subjects to suit his hearers, and more than once he enlarged later in book form on some research that he had taken up for the purposes of an address. Masterly and elegantly phrased as his lectures were, they never failed to interest; but in delivering them he was not the equal of many a far less able man in rousing enthusiasm in his audience.

His retirement from the Geological Survey in 1901 enabled him to increase his other activities. He had been elected to the Royal Society in 1865, had served twice on the Council, and had held the posts of Vice-President in 1885–87 and of Foreign Secretary in 1889–93. After his retirement he served as Secretary in 1903–8 and was President in 1908–12. In 1912 the Society celebrated its 250th anniversary, and it fell to Geikie to receive an unexampled gathering of distinguished men of science from all parts of the world, and to preside at the various functions. During this period of his life he wrote six or more books, besides bringing out new editions of his Advanced Text-Book and several others. He had served on several Departmental Committees and on Royal Commissions; at the age of 85 he was appointed Chairman of the Royal Commission on Trinity College, Dublin.

The eminence attained by Geikie in science and letters was acknowledged by the bestowal of honours from all parts of the world. Space will admit of the mention of those only that he most valued. By our own Society he was awarded the Murchison and Wollaston Medals, by the Royal Society a Royal Medal, and from the Royal Society of Edinburgh he twice received the Macdougal-Brisbane Medal. He was also the Hayden Gold Medallist of the Philadelphia Academy of Natural Sciences, the Livingstone Gold Medallist of the Royal Scottish Geographical Society, and the Gold Medallist of the Institution of Mining & Metallurgy. Honorary degrees were conferred on him by the Universities of Oxford, Cambridge, Dublin, Glasgow, St. Andrews,

Aberdeen, Liverpool, Birmingham, Leipzig, Upsala, and Prague He was an Officer of the Legion of Honour and honorary member of a great number of the leading scientific societies at home and abroad. He was three times President of Section C of the British Association, and was President of the Association in 1892. In 1910 his distinction in the world of letters was acknowledged by an invitation to take the Presidential Chair of the Classical Association. He was a Trustee of the British Museum and a Governor of Harrow School. In 1891 he was knighted, and in 1907 created a K.C.B. In 1913 he received the crowning honour of his life, the Order of Merit.

This crowded life closed peacefully on November 10th, 1924. Towards the end gradually failing strength prohibited him from leaving the home that he had made at Haslemere, but his mind remained active to the last, and it was not until a few months before his death that the busy pen was allowed to rest. From early youth until old age could no longer be denied his career had been one of uninterrupted progress. When fresh from school he attracted the attention of the most eminent geologists of the time; in the profession which he chose and in the Societies which he joined he rose to the highest posts; in every country he visited he won the respect of its most eminent scientific men; every function that he attended gained in significance and dignity by his presence.

The keynote of his success was industry directed by sagacity. An innate love of writing and a remarkably retentive memory kept his pen always busy. The most arduous day's work in the field or the office put no check upon his reading and writing, and both were of the best, for he loved a good author and had himself cultivated the power of narrating the marvels which he had wrested from Nature in language worthy of the theme. A clear if somewhat cold judgment controlled his actions, but in his biographical work the coldness was masked by a studied kindliness of expression. Though he made many friends at home and abroad, his sympathies with his fellow-men were somewhat overshadowed by his love of Nature and passion for work. He did not seek collaboration, but preferred to work single-handed, nor could he brook criticism.

Archibald Geikie now takes his place in history as one who has enriched the world by his labours and his writings, and as one of those outstanding leaders who has raised the science of geology to a higher plane than that on which he found it. [A. S.]

WILLIAM WHITAKER was born in Hatton Garden on May 4th, 1836. He was educated at St. Alban's Grammar School, and afterwards at University College, London, where he devoted himself chiefly to chemistry, but studied geology under Prof. John Morris. He took the B.A. degree at the University of London. His good work on the Mesozoic and Kainozoic rocks of the South-East of England received the commendation of Murchison, the Director-General of the Geological Survey, and of Ramsay. It is said that the former proposed that he should be shifted to areas where there were good hard rocks, not 'soft squashy' materials, but the latter declared that Whitaker preferred these. So he was allowed to continue his work in the South-East, and took a considerable share in the construction of the fine Old Series maps of that part of the kingdom. He lived to see a new survey commenced by younger men, who, however, owed much to his previous labours and to his counsel and assistance. He is perhaps best known to geologists in general by his publications on the Geology of the London Area; but one of the most important consequences of the experience that he gained in his work on the Geological Survey was the publication of his paper on 'Subaërial Denudation, & on Cliffs & Escarpments of the Chalk & Lower Tertiary Beds'. It was read before the Geological Society as early as 1867, but was only published in brief abstract in the Quarterly Journal. It appeared, however, in full in the Geological Magazine, and at once attracted attention. It finally disposed of the belief, which still lingered in some quarters in this country, and had considerable vogue on the Continent, that escarpments were due to marine action. Speaking of this, Charles Darwin himself declared that Mr. Whitaker had had 'the good fortune to bring conviction to the minds' of his fellow-workers by means of a 'single memoir'.

He retired from the Survey in 1896, but long after continued to contribute to its publications memoirs on the water-supply of the different counties, in which full particulars were given of the wells and the information that they afforded of the strata passed through and the level of the water-surface. He now enjoyed considerable private practice as a water engineer, and was a prominent and welcome figure at the meetings of the Institution of Water Engineers, of which he was an honorary member, and his unusually free and unconventional contributions to the discussions were much appreciated. As an expert witness in the

Committee Rooms of the Houses of Parliament, he impressed his hearers by his ease of manner and avoidance of over-emphasis.

In our own Society, into which he was elected in 1859, he was a familiar figure, both at the meetings and in the Council Room. He was President in 1898–1900: he received the Murchison Medal in 1886, the Prestwich Medal in 1906, and the Wollaston Medal in 1923. His contributions to discussions were always original and to the point. He was a frequent attendant at the meetings of the British Association and its excursions, and was for some time a Member of Council. He was President of Section C at Ipswich in 1895. He was elected to the Royal Society in 1887, and served on the Council in 1907–1909.

It was, however, in the assistance which he afforded to scientific societies, consisting largely of amateurs, that he rendered the most valuable services to our science. He was elected an Honorary Member of the Geologists' Association in 1875, without having been an ordinary member. He was President in 1900-1902 and again in 1920-22, and was a regular attendant both at meetings and at excursions. He was long a resident in Croydon, and a prominent member of the Croydon Natural History Society. Indeed, the strong position that it has maintained and good work that it has done have been largely due to his association with it. He was President in 1899, 1900, and 1911. He was a strong opponent of the bill of the Croydon Corporation to enable it to pull down Whitgift's Hospital, and was a member of the deputation to the Ministry of Transport that succeeded in defeating the measure. He was also on the Croham Hurst Preservation Committee, which secured the purchase of that fine geological outlier by the Corporation and its dedication as a public open space. He was also President of the Essex Field-Club, of which he was an original Honorary Member, during 1911-14, and of the Hertford Natural History Society in 1897-99. President of the South-Eastern Union of Scientific Societies at its Congress at Rochester in May 1899.

The 'Hints' to those engaged in research-work in Geology—contained in his Presidential Address to the Geologists' Association in 1922 illustrate aptly his genial, helpful attitude to his fellow-workers, as well as his shrewd common-sense. He made many friends but never an enemy, and his absence will long be sorely felt wherever geologists are gathered together.

He died at Croydon on January 15th, 1925.

The death of Sir Jethro Justinian Harris Teall on July 2nd, 1924, has removed from our midst one of the most familiar figures at the meetings of the Society and one of the most famous names that has graced its rolls. Since the publication of his 'British Petrography' in 1888 he had been recognized as a leading British exponent of this subject, and with the lapse of time his exhaustive knowledge of the literature, brilliant originality, and sound critical judgment had made him the acknowledged leader of British workers in this field. He was elected a Fellow of the Geological Society in 1873. He was Secretary from 1893 to 1897, and President in 1900-1902. His Presidential Addresses are models of luminous exposition and philosophic breadth of view. In 1889 he was Bigsby Medallist, and in 1905 he received the Wollaston Medal. Many of his early papers were published in our Quarterly Journal, each of them a solid contribution to science, abreast of the most recent researches, and filled with new observations of great value. He was elected a Fellow of the Royal Society in 1890.

Born in 1849, the son of a private gentleman, who died before his son was born, he was educated at private schools, and went to St. John's College, Cambridge, in 1869. Three years later he obtained a First Class in the Natural Sciences Tripos, and in 1875 was elected to a Fellowship of his College. In 1874 he won the Sedgwick Prize for an essay on 'The Potton & Wicken Phosphatic Deposits'; this was the first award of the prize. He devoted his time to petrological research, inspired in some measure by the teaching and example of Prof. T. G. Bonney, who was a tutor of his College, but he combined this with a large amount of University Extension lecturing on geology and physical geography in many English towns. Ultimately, he settled at Kew, and pursued his studies, which bore fruit in the publication of his British Petrography' (1888). This work contained not only the results of the author's researches in such varied districts as Cornwall, Northumberland, and the Scottish Highlands, but summarized also the whole descriptive literature of the subject, and was rendered especially valuable by the discussions on chemical topics and on the diagnosis of minerals which met a need urgently felt by all workers in this department. His 'British Petrography' served a whole generation as the standard work of reference, the best text-book for students, and the best model on which petrographical descriptions should be framed. Its history was rather chequered, as, owing to the failure of the publishers when the work was in the press, the author himself took the publication in hand. This explains how it was never actually completed: the initial parts had been planned on too grand a scale, and the closing chapters had to be greatly abridged. The excellence of the illustrations is a special feature of the book, and Teall was assisted by many enthusiastic helpers, such as Frank Rutley, Felix Oswald, and, above all, Lady Teall, some of whose beautiful drawings are perfect examples of the best class of microscopical illustrations.

In 1888 Teall joined the Geological Survey as Petrographer, on special appointment. Sir Archibald Geikie was then involved in the mapping of the North-West Highlands, and wisely decided that the highest petrographical skill should be recruited for the service. For thirteen years Teall filled this post. The task was onerous, but he entered on it with great enthusiasm. A diligent though by no means rapid worker, scrupulously careful to the last degree, he overtook a great deal of work, and made very few mistakes. In all that he did he showed great acuteness, combined with extreme caution, and few official scientists who have had as much to do as he did have had so few corrections and additions made to their work by their successors. He came to be regarded by his colleagues as almost infallible. Of his numerous contributions to Geological Survey Memoirs the principal are his chapters in the 'North-West Highlands' and in 'The Silurian Bocks of Scotland '.

In 1901 Teall became Director of the Geological Survey: for a time he had charge also of the Irish Geological Survey, but this was disjoined in 1905. He devoted almost his whole time to administrative work and to editorial duties, and, although he had no special liking for these activities, he achieved great success. He showed great energy in initiating new projects, encouraging economic work, improving the publications, especially the maps, and in stimulating the scientific enthusiasm of his staff. For this he had two great qualifications, perfect impartiality and complete disinterestedness. These secured for him the hearty support of the Board of Education and the faithful collaboration of his staff, and often rendered reorganizations possible which otherwise might have failed. In a few years he had greatly enhanced the reputation of the Survey, both in economic and in scientific circles. and in 1914, when he handed over the reins to Sir Aubrey Strahan, he left the Institution infinitely stronger than it was when he took office. During this period he necessarily was too much engaged otherwise to have time for scientific investigation, but in his frequent visits to the field his sagacious council was highly esteemed by all who were privileged to obtain it.

In 1916 he received the honour of knighthood, and after his retirement he occupied himself with many activities, returning to the study of British petrography and of his fine collection of rock-sections, which after his death Lady Teall bestowed on Cambridge University. Sir Jethro Teall was President of the Geologists' Association from 1898 to 1900, and President of the Geological Section of the British Association in 1893. He was Sc.D.(Dublin), D.Sc.(Oxford), Sc.D.(Cambridge), and LL.D. (St. Andrews). An honour of which he was especially proud was the Delesse Prize of the Academy of Sciences in Paris, awarded to him in 1907. [J. S. F.]

CHARLES WILLIAM ANDREWS, who died on May 25th, 1924, aged 58, made many important contributions to our knowledge of Vertebrate Palæontology. Born at Hampstead, he graduated in both arts and science in the University of London, and in 1892 he obtained an assistantship in the Department of Geology in the British Museum (Natural History). Here he took part in curating the fossil vertebrata, and soon began to extend his work to original research. At first interested in birds, he described and discussed many important specimens from the Southern Hemisphere, and in later years he made known a primitive tropic bird from the London Clay of Sheppey, besides remains of the largest discovered flying bird from the Eocene of Southern Nigeria. Dr. Andrews also paid much attention to the marine Mesozoic reptiles, of which the Leeds Collection from the Oxford Clay of Peterborough added so much to our knowledge. He wrote several papers on these remarkable fossils, including one on the skull of Pliosaurus published in the Society's Quarterly Journal in 1897; and, when the whole collection had been received by the British Museum, he prepared a complete 'Descriptive Catalogue of the Marine Reptiles of the Oxford Clay' in two volumes, which were published by the Trustees in 1910-13. In subsequent years Dr. Andrews continued his interest in the same reptiles, and so recently as 1922 he contributed to the Society's Quarterly Journal a paper on a new Plesiosaurian from the Wealden of Sussex. Dr. Andrews, however, will be best remembered by his discoveries of fossil mammals in the Tertiary formations of Egypt. In 1900, when he showed the first symptoms of an illness which afflicted him for the rest of his life, the generosity of a Trustee of the British Museum enabled him to recuperate for some months in Egypt. There he joined Mr. H. J. L. Beadnell, then of the Egyptian Geological Survey, in the Fayûm, and he soon detected mammalian remains in the early Tertiary freshwater deposits of that region. At the expense chiefly of the late Mr. W. E. de Winton, he then paid repeated visits to Egypt between 1902 and 1906, and both he and Mr. Beadnell collected extensively from every favourable exposure of the rocks. Dr. Andrews, in a series of papers, thus showed that at least two ancestors of the Proboscidea occurred in the Eocene and Oligocene deposits of Northern Africa, and helped to explain the origin and evolution of this group of mammals. He also discovered important new facts bearing on the evolution and relationships of the Hyracoidea, Sirenia, and Cetacea. The results were summarized in 1906 in his 'Descriptive Catalogue of the Tertiary Vertebrata of the Fayûm, Egypt,' which was published by the Trustees of the British Museum, and will always remain one of the classics of Vertebrate Palæontology. In later years Dr. Andrews made many other important contributions to our knowledge of the fossil mammals of Africa, the latest being his recognition of a fragment of Chalicotherium in 1923 from a late Tertiary deposit in Uganda. At the same time Dr. Andrews was an accomplished geologist, and his survey of Christmas Island in the Indian Ocean in 1897-98 led to an excellent description of that remote oceanic island. He was ever ready to place his wide knowledge and keen critical insight at the disposal of others, and his personal kindliness endeared him to a large circle of friends. His influence on the progress of geology and palæontology was far reaching, and his premature death is a sad loss to science. Dr. Andrews was elected a Fellow of our Society in 1894, and to him were awarded the Lyell Fund in 1896 and the Lyell Medal in 1916. He also served on the Council, and was a Vice-President in 1910-12, and again at the time of his decease. He was elected a Fellow of the Royal Society in 1906. [A. S. W.]

The death of Prof. Grenville Arthur James Cole, at his home in Carrickmines (County Dublin) on April 20th, 1924, removes from the Geological Society's list one of its most distinguished Fellows. He was a man of world-wide reputation.

equally distinguished by his brilliance as a writer and by the effectiveness of his work as a scientific geologist, a combination of qualities rarely displayed in so high a degree of excellence as they were by him.

Cole was born in London on October 21st, 1859. His father was an architect who gave much time to the study of geology and to the making of geological photographs. His grandfather, although a solicitor, was keenly interested in collecting minerals. Cole's enthusiasm for geology and mineralogy, the two dominant subjects of many in which he was interested, may thus almost be said to have been inherited.

He was educated at the City of London School, and while still there commenced the study of geology and mineralogy at the Royal School of Mines, where he ultimately became Demonstrator, and in that capacity he assisted Prof. J. W. Judd in organizing systematic laboratory geological instruction, in which they were pioneers. He himself gave special attention to petrology, and found his chief interest in the early French workers on the subject.

In 1890 Cole became Professor of Geology at the Royal College of Science, Dublin, a post in which his routine duties were at the outset fortunately very light, leaving him ample time and opportunities for field-work, study, and research, a circumstance of which he took the fullest possible advantage. He became the leading authority on the geology of Ireland, and the numerous popular articles which he wrote on this subject were remarkable for the way in which they fascinated the general reader, while sacrificing nothing of the accuracy of strictly scientific writing. At a later date his Professorship was extended to mineralogy, and still later he organized a course of geological lectures and laboratory work, including soil physics, for students in agriculture. He was also Curator of Geology & Minerals at the Dublin Museum. In 1905, when the Irish section of the Geological Survey was placed under the Department of Agriculture & Technical Instruction for Ireland, Cole became Director of the Survey.

He travelled extensively, especially on the Continent, where he spent many holidays awheel, and made an excellent collection of geological photographs illustrative of his travels. His lectures on geology were invariably illustrated by excellent lantern-slides, many of which were prepared from his own negatives. As a teacher, he ever strove to make things plain and interesting. He had a rich fund of humour, which he never failed to exploit when

he could do so effectively. Science to him was a thing to be fitted into the general human scheme of things as one of the manifold needs of life; and it was for this purpose that he strove to make it of real interest. He never allowed his students to forget that minerals were chiefly interesting as the constituents of rocks, and that rocks built up the Earth, on which Man was the all-important denizen.

It was the largeness of his outlook, together with his eloquence and his marked literary gifts, that accounted alike for his grip as a lecturer and his popularity among a wide circle of readers, and made him almost as keenly interested in geography, travel, and educational methods as in geology. To these attainments were added the magnetism of an attractive personality.

He wrote upwards of 100 substantial scientific papers, covering all branches of geology, including petrology, physical geology, stratigraphy, and palæontology. Perhaps the more important were those on the composite gneisses at many localities in the North-West of Ireland. In opposition to prevalent opinions, Cole favoured the view that assimilation by igneous rocks had played an important part in the process of igneous intrusion, and called to witness much evidence collected by him in various parts of Tyrone and Donegal.

He was the author of two excellent college books: 'Aids in Practical Geology', which has gone through several editions, and 'Outlines of Mineralogy for Geological Students'. Still more notable are his popular works: 'Open-air Studies in Geology', 'The Changeful Earth', 'Rocks & their Origins', 'The Growth of Europe', 'Ireland the Outpost', and 'Common Stones'. His authorship was remarkable for the wide knowledge displayed of the literature of the subject with which he was dealing, and his success in giving to the reader the full benefit of it.

Elected a Fellow of this Society in 1881, Cole in 1889 received an award from the Murchison Geological Fund, and in 1909 the Murchison Medal was awarded to him. As President of the Geological Section of the British Association in 1915, he delivered an excellent and stimulating address on earth-movement and other aspects of dynamical geology. In 1917 he was elected a Fellow of the Royal Society, and in 1919 he was President of the Geographical Association.

Cole's hobby was cycling, 'especially as a means of travel', and to cycle with him was a test of endurance. Although a man of abnormally small stature, and severely handicapped for many years

by arthritis, he rode a machine of the heavy roadster type, usually provided with a heavy carrier. The distance that he could travel on rough roads, the pace that he could maintain, and the amount of interesting conversation that he could throw off, not only on geology and scenery, but on things in general, was a constant source of wonderment to his fortunate companions, who were left with no alternative but to believe that Cole must have hitched his heavy roadster to a star.

His vitality was amazing. He rose early, retired late, and crammed the day with achievement. Despite his abounding energies, he maintained a remarkably equable temper. The emergency ever found him cool and resourceful. Always genial, nothing could depress him, not even the dire malady that afflicted him so long and ultimately laid him low. Up to the end his spirit emerged serene through his affliction, and his correspondence gave no hint that he was otherwise than fit.

Grenville Cole's character and personality epitomized the best in human nature, and it may indeed be said of him, in the words of his beloved Marlowe, that he 'inclosed infinite riches in a little room'. He found his greatest pleasure in seeking opportunities for service, which he rendered freely to all comers; and he was a help and source of inspiration to all who had the good fortune to know him or to work with him.

The greatest memorial that he could have wished would have been that his adopted country should maintain the splendid facilities for scientific and economic work, in the development of which he spent so large a part of his life and energies. [T. C.]

Robert Kidston, who was elected a Fellow in 1881, died on July 13th, 1924, at the age of seventy-two. He died, as he would have wished, when engaged in the examination of a collection of examples of the British Carboniferous Flora, a flora to which he devoted the greater part of more than forty years of his life. With the exception of a short tenure of the post of Demonstrator in the Botanical Department of the University of Edinburgh, Kidston confined himself to research. He was in close touch with the Geological Surveys of England and Scotland. By his own work in the field, and with the help of many correspondents, he amassed an exceptionally complete collection of specimens, both impressions and petrifactions, the value of which is greatly enhanced by the meticulous care bestowed upon its arrangement

and labelling. It is impossible in a short sketch to do justice to his researches: he was deservedly regarded for many years as the leading British authority on the taxonomy of Carboniferous plants, and to him, more than to any other palæobotanist, we owe the recognition of the value of botanical species as aids to geological correlation. In collaboration with the late Prof. Gwynne-Vaughan he published several papers on the fossil Osmundaceæ and on other extinct types, which made a wide appeal to botanists and illustrated the evolutionary importance of the comparative study of a succession of related forms. The more recently published papers under the joint authorship of Kidston and Lang-the last of which has appeared since the death of the senior author—on the Middle Devonian plants of Rhynie are the most valuable and sensational contributions to our knowledge of pre-Carboniferous vegetation that have so far been made in this or any other country. Few men have left a more substantial and, one may safely add, a more enduring record of consistent and thorough original work. The Murchison Geological Fund was awarded to him in 1887, and the Murchison Medal in 1916.

Robert Kidston was an accomplished naturalist; he was equally at home in giving practical instruction to his gardener and in discussing, with a white clay pipe nearly always alight, complex problems suggested by the plants of the more remote epochs of the world's history. A highly skilled photographer and draughtsman, he was his own illustrator, and always demanded a very high standard. Though primarily a student, he was also a man of affairs who had a keen sense of duty to the State. Kidston had many Scottish traits strongly developed: difficult to deflect from a particular line of thought and from a firmly rooted opinion, he was always ready to acknowledge an error and to give careful consideration to opposing arguments. He was dogmatic, and on occasion provocative in his denunciation of those whose actions or opinions met with his vigorous disapproval. He was also a staunch friend who inspired affection by his generosity, his honesty, and his boyish enthusiasm. To many junior workers he was an inspiration; he was always absolutely natural and sincere. Difference in age was ignored; the important thing was a sense of comradeship in a common quest.

The fact that of the ten projected Parts of the Memoir on the Carboniferous Flora which were being published by the Geological Survey only four were completed, emphasizes the tragedy of the loss which we have sustained; but one hopes that the notes and photographs which he had already prepared may enable other hands to complete an undertaking as he would have wished it to be completed, and worthy to be a memorial of one who was not only a great paleobotanist, but also a man whom those who knew him well loved and respected. [A. C. S.]

Dr. HENRY KEYES JORDAN, who was elected a Fellow of this Society in 1865, died at Llandenny (Monmouth) on December 29th, 1923. Born at Bristol in 1838, he received his early training as a mechanical engineer; but almost at once he turned his attention to coal-mining, first in the Forest of Dean, and later in South Wales. His earliest paper on the subject appears to have been 'The Pencoed, Mynydd-y-Gaer, & Gilfach-Goch Mineral Districts' published in 1876, and followed in 1877 by a paper on 'Coal-Pebbles & their Derivation' read before this Society. Later, between 1908 and 1915, he published four important papers on the South Wales Coalfield, which are recognized as standard works on the subject. He became a member of the South Wales Institute of Engineers in 1873, was President in 1898, and was the first recipient of the gold medal of the Institute, which was awarded on his paper, read in 1903, 'On the South Trough of the Coalfield, East Glamorgan'. Later, the Institute made him an honorary member—an honour very rarely conferred. He was a D.Sc. of the University of Wales. In addition to his professional work in the coalfields, Jordan found time to make a very fine collection of British marine mollusca, and to contribute several papers on living mollusca to the Bristol Naturalists' Society; also to publish between 1866 and 1870 a Catalogue of British Mollusca, based on Gwyn Jeffreys's 'British Conchology'. His collection of shells was sold some years ago to Mr. T. R. le B. Tomlin, of St. Leonards-on-Sea. [W. C. S.]

RICHARD FUGE GRANTHAM, a very distinguished civil engineer, died in his eightieth year on September 26th, 1924. He was born on October 27th, 1845, and was elected a Fellow of this Society in 1892, the year after the death of his father, Richard Boxall Grantham, F.G.S. His father and his grandfather before him, both civil engineers of considerable reputation, had been chiefly interested in drainage and river problems, and R. F. Grantham carried on their work, rendering great service to the

Government and to the Ecclesiastical Commissioners by his labours in connexion with the reclamation of areas in the Wash, and the prevention of coast-erosion. For a paper on Sea-Defences he received the gold medal of the Society of Engineers in 1897, and as recently as 1916 he received a Telford premium from the same Society for a paper on Arterial Drainage. He continued in full activity until within a few months of his death. [W. C. S.]

Dr. WILLET GREEN MILLER was born in Norfolk County (Ontario) on July 19th, 1866. He was educated at the County School, Port Rowan High School, and the University of Toronto, where he graduated in chemistry, mineralogy, and geology in 1890. He always referred gratefully to the instruction and inspiration which he received from Prof. Chapman, under whom he worked first as undergraduate, and then for three years when he held a Fellowship in Geology. In 1893 he was appointed lecturer at Queen's College, Kingston, and afterwards became Professor. He was the first to show that X-ray methods could be employed to distinguish carbonaceous minerals (including diamonds) and those consisting mainly of aluminium from others. He was, too, chiefly responsible for the development of the corundum industry in Canada. His work in the direction of mineral development was so much appreciated that, in 1902, the Ontario Government created the post of Provincial Geologist so that it might reap the fullest advantage of his experience and abilities in that position. In the succeeding year his opportunity came. A specimen of arsenide of nickel, which had been obtained in railway excavations in Northern Ontario, was sent to the Department of Mines to be assayed for copper. Thinking that another Sudbury had been discovered, he started at once. He found not only nickel, but silver and cobalt, and he himself gave to the new metalliferous locality the name of 'Cobalt' by inscribing the words 'Cobalt Station' on a board which he placed on a post by the railside. He was mainly responsible for the systematic organization of the mining work in this area and the fields on the north, and for the scientific manner in which it was carried out.

But he was not only a great expert on mineral exploitation, he was a great geologist; and it was because his work was guided by scientific knowledge and intelligence that its value was so widely recognized by mining men. He gave to geology and geologists, we are told, an entirely new status in the mining industry of Canada.

His work on the pre-Cambrian rocks will be fresh in the minds of geologists in this country, both from his lectures over here and from the excursions which he conducted when the International Congress met at Toronto, and during the recent visit of the British Association.

In 1915 he was appointed a member of the Royal Ontario Nickel Commission, and two years later he was appointed the Canadian representative on the Imperial Mineral Resources Bureau, and remained a Governor till his death. During this period he rendered valuable assistance in the execution of its work. He travelled widely. In addition to semesters spent in the universities of Chicago and Harvard, mainly for the purpose of understanding his fellow-workers and their methods, he visited not only the British Isles, but Mexico, Cuba, Northern Europe, South Africa and Australia, and New Caledonia.

He was elected a Fellow of this Society in 1918. He was a Fellow of the Royal Society of Canada, M.A. and Honorary LL.D. of the University of Kingston, and was a Trustee and member of the Board of Governors. He was a member of the Society of Economic Geologists, of the Geological Society of America, of the Canadian Institute of Mining & Metallurgy, of the Royal Canadian Institute, and of the Institution of Mining & Metallurgy, from which body he received the Gold Medal in 1915.

He was recently elected President of Section C of the British Association for the Advancement of Science, and was to have presided over the meetings of that section at Southampton in the coming summer. He died on February 4th, 1925.

Sir Byron Edmund Walker, K.C.V.O., LL.D., D.C.L., who was elected a Fellow of the Society in 1891 and who died on March 26th, 1924, has been described as one of Canada's greatest bankers; but he was much more besides, and science, letters, and art in Canada owe much to his patronage. He was born at Seneca (Ontario) in 1848, commenced his banking career at the age of twenty, and was manager of the Canadian Bank of Commerce at thirty-eight. Despite his heavy business responsibilities, he seems to have found time to take an active interest in art and science. He was an authority on Canadian history. He was Chairman of the Board of Governors of Toronto University from 1907, and was elected Vice-Chancellor in 1924. He was President of the Canadian Institute in 1899–1900, and his deep

interest in geology is shown by his two Presidential addresses: one in 1899 on the importance of fossils, and the second in 1900 on Canadian Surveys and Museums, and the need for expenditure thereon. In 1901 he published, in the Canadian Records of Science, a 'List of the Published Writings of Elkanah Billings (Palæontologist to the Geological Survey of Canada from 1856–1876).' [W. C. S.]

By the death on February 5th, 1924, of Major-General Douglas Alexander Scott, C.B., C.V.O., D.S.O., R.E., the Society lost one of its oldest Fellows. General Scott was born on December 14th, 1848, and was elected a Fellow of the Society in 1872. He was gazetted to a lieutenancy in the Royal Engineers in 1870. In 1876 he was appointed Deputy Consulting Engineer for guaranteed railways to the Government of India, and was in charge of the Royal train when the late King Edward travelled through India in that year. He fought in Egypt in the suppression of Arabi Pasha's rebellion in 1882, and was Director of Sudan Railways in the campaign of 1884–85.

Subsequently he held many important appointments in Home commands, and became Colonel-Commandant, Royal Engineers, in 1921. [W. C. S.]

HERBERT THOMAS BURLS, M.B.E., who had joined this Society in 1880, died suddenly at his London residence on April 16th, 1924. After having studied at the Royal School of Mines from 1874 to 1878, he did his early work as a mining geologist on the Derwent Lead-Mines and in the copper-mines of Cornwall. In later years he was at work in various mining districts in South Africa, but after 1898 he devoted himself almost entirely to petroleum geology. During the War he was geologist to Munitions Mineral-Oil Production, and for his services he was made a Member of the Order of the British Empire. At the time of his death he was conducting experiments on a process for eliminating sulphur from Dorset oil-shales. In addition to being a Fellow of this Society, he was a Fellow of the Royal Geographical Society, a Member of the Institution of Mining & Metallurgy, of the Institution of Mechanical Engineers, of the Iron & Steel Institute, and of the Mineralogical Society, and was a familiar figure at many of the meetings of these various bodies.

THOMAS WILLIAM DANBY, who died at the age of 84 on March 21st, 1924, at Seaford in Sussex, was elected a Fellow of this Society in 1875. He was born on March 10th, 1840, studied at the Royal School of Mines from 1857 to 1860, and gained the Duke of Cornwall's Scholarship in 1858, and both the Edward Forbes and De la Beche Medals in 1860. Proceeding to Cambridge, he entered at Gonville & Caius College, but transferred to Queens' in 1862. In 1863 he was elected to a Foundation Scholarship at Downing, and in the following year he headed the list in the Natural Sciences Tripos. In 1867 he was appointed Lecturer in Natural Science at Trinity College, and was made a Fellow of Downing. From 1870 to 1871 he was a University Demonstrator in Chemistry under the late Prof. Liveing, a post which he relinquished to become one of Her Majesty's Inspectors of Schools in 1872. He published in 1875 an English edition of Prof. C. W. C. Fuchs's 'Practical Guide to the Determination of Minerals by the Blowpipe'. He was twice Examiner in Chemistry in the Natural Sciences Tripos—once in 1870, and again in 1888. His Fellowship at Downing terminated in 1879. He became a Divisional Inspector of Schools for the South-East of England in 1893, and retained this post until his retirement in 1904. He was one of the original members of the Mineralogical Society, a friend of Hugh Miller's, and an intimate friend of the late Sir Lazarus Fletcher. Though much troubled by partial blindness in his later years, he retained an active interest in a variety of subjects, and his kind and courtly manner and keen sense of humour have made his memory a very pleasant one to those who were privileged to know him. [W. C. S.]

In Edwin A. Walford, who died in March 1924, our science has lost a zealous worker, whose studies extended over a wide field. He was well read in the literature of the subject, both English and foreign, and especially devoted himself to the geological investigation of the region around Banbury.

His published papers are recognized as an important contribution

to our knowledge of the Jurassic System.

In the course of his researches he amassed a remarkably fine collection of Jurassic fossils: it now forms a much valued part of the collections in the Oxford University Museum.

He was elected a Fellow of the Geological Society in 1882, and an Award was made to him from the Lyell Geological Fund in 1892. He had meanwhile contributed four papers to the Society's Quarterly Journal, followed by three more in 1894 and 1902. [W. J. S.]

Colonel ALISTER WILLIAM JAMIESON, late of His Majesty's Indian Army, the son of Major-General J. W. H. Jamieson, died at his residence at Worthing on July 20th, 1924. He took a keen interest in geology, and was elected a Fellow of this Society in 1913. His only published papers are on prehistoric subjects, but he spent much time in collecting worked flints from the surface in Sussex and Hampshire, and in mapping that area on a geological basis, his endeavour being to show the type of implements that was generally associated with 'Clay-with-Flints'. His maps and notes have been deposited in the Department of British & Mediæval Antiquities at the British Museum, where a selection of the flints is exhibited; and, although surface-finds do not prove the point, the 'Clay-with-Flints' is now known to produce undoubted implements, as at Cudham and Eynesford (Kent). [R. A. S.]

DAVID WOOLACOTT was a prominent member of the long line of geologists who received their teaching and inspiration from the late Prof. G. A. Lebour. Unlike many of the others, whose work was spread over every continent, he confined his geological researches almost entirely to the North-East Coast, and his death on August 4th, 1924, robs that area of a fund of local geological knowledge much of which cannot be replaced. His early interest was mainly in the superficial geology of the area, and was published in a series of papers on the relics of high-level raised beaches, the glacial and fluvioglacial deposits, and the preglacial land-surface. He established the existence of several important buried valleys, and showed that substantial modifications of the drainage-system had resulted from the glaciation. The results of this period of work are largely summarized in papers 'On the Superficial Deposits & Pre-Glacial Valleys of the Northumberland & Durham Coalfield' (Q. J. G. S. 1905) and 'On the Origin & Influence of the Chief Physical Features of Northumberland & Durham' (Geogr. Journ. 1907). A second period began with the recognition in 1906 that intraformational earth-movement had occurred in the Northern Coalfield, and Woolacott vigorously pursued this clue in explanation of many of the remarkable structures of the Durham Permianthe astonishing brecciation of great thicknesses of strata, the breccia-gashes, and the local absence of parts of the normal sequence. Whether or not movement played so large a part as he suggested, we are indebted to him for much the fullest account both of the structures and of the strata that they affect (Univ. Durham Phil. Soc., Monogr. I, 1909, and Mem. IV, 1912).

After the period of absorption in military duties during the War, Woolacott returned with fresh energy to his former problems. The stratigraphy of the North-Eastern Permian was revised in a paper in the 'Geological Magazine' (1919). Its unconformable relation to the Coal Measures was further emphasized by the discovery of 'Upper' Coal Measures near Sunderland, and from this followed a renewed interest in Coal-Measure correlation, expressed in accounts of the borings at Cotefield Close and Crook (Geol. Mag. 1919 & 1923). The superficial geology received fresh attention, following the discovery of demonstrative evidence of the 60-foot raised beach at Easington (Geol. Mag. 1920 & 1922). This was followed by a reconsideration of the whole Glacial sequence in the North-East (Geol. Mag. 1921), the last contribution to which was completed a few days before his death, and is now in course of publication.

Born at Sunderland on July 1st, 1872, he had only just completed his 52nd year. He was Lecturer and afterwards Reader in Geology in Armstrong College, in the University of Durham, from 1906 until his death.

He was elected a Fellow of our Society in 1897, and in 1920 the Murchison Fund was awarded to him. [G. H.]

Dr. George Abbott was born on March 25th, 1844, and died on January 12th, 1925. He was elected a Fellow of this Society in 1901. He was a Member of the Royal College of Surgeons and Licentiate of the Royal College of Physicians, and for the greater part of his life practised at Tunbridge Wells, where he was responsible for many important local activities. In 1890 he started technical classes which developed into a Technical Institute, ultimately taken over by the Town Council. In the early 'eighties he was instrumental in forming the Tunbridge Wells Natural History Society. In 1896, in conjunction with the Rev. T. R. Stebbing, he founded the South-Eastern Union of Scientific Societies, of which he was for some years the General Secretary. In its Transactions most of his published work appeared. He also

lxxviii

contributed to the Proceedings of the Geologists' Association. He assisted in the formation of the local museum, and in recent years devoted much time to it. He interested himself, too, in the promotion of the study of Nature in elementary schools, and supplied specimens to school museums both in Tunbridge Wells and elsewhere. He was a keen geologist, his chief interest being in the structure of concretions, especially those in the Magnesian Limestone near Sunderland. He presented type-series of these last to the Imperial College of Science & Technology, as well as to other institutions.

EVAN RICHARD STANLEY, elected a Fellow of this Society in 1914, late Government Geologist of Papua, received his training while serving as a student assistant in Adelaide University between the years 1903 and 1910. During this time he aided Sir Douglas Mawson in his study of the Broken Hill region, and published three papers on the volcanic rocks of Mount Gambier and Kangaroo Island. He was appointed Government Geologist of the Territory of Papua in 1911, and was at first associated with visiting experts. Dr. A. Wade and Mr. J. E. Carne, in the preparation of their general reports on the occurrence of coal and petroleum in the Territory, while he also prepared independently several reports on metalliferous fields, and especially on the geological features of the islands of the D'Entrecasteaux and Louisiade groups. His interest in the broader structural features of the Territory appears to have been greatly stimulated by the summary of the known facts prepared by Sir T. W. Edgeworth David for the Australian Meeting of the British Association in 1914 (in 'The Federal Handbook'), and two years later he traversed the backbone of Papua, the great Owen Stanley range, and obtained very many new observations from studies of the coastal districts of the long south-eastern promontory and Cape Vogel Peninsula, as well as data gathered farther west along the southern coastal and foothill districts. This he summarized in a report presented to the Australasian Association for the Advancement of Science in 1921, which was afterwards published as a Bulletin (No. 7) of the Territory of Papua. In this he sketched the main structural lines, the axes of folding and of faulting in the region, and indicated their relation to neighbouring areas, and further emphasized the immensity of the later Tertiary and Pleistocene crust-movements. He was then attached as Geologist to the Commonwealth Scientific Expedition

which explored the coastal districts and the Ramu River Valley of the New Guinea Territory, late German New Guinea, and he published in the official report to the Mandates Commission of the League of Nations (1922) a very comprehensive account (with abundant illustrations and map) of the geology, physiographical features, and natural resources of that great territory (90,000 square miles), together with an ethnological and linguistic appendix, incorporating a summary of as much of the earlier German work as he was able to consult. Further information, especially in regard to New Britain and the adjacent islands, appeared in his 'Notes on the Structural Relations of the Volcanic Rocks of the Late Tertiary & Mesozoic Deposits of New Guinea', presented to the Australasian Association in the following year. In this year also he drew up a comprehensive summary of the results of his twelve years of research in Papua, forming a well-illustrated series of notes (56 pp.) accompanying the first geological map of that Territory yet published. He remarked, however, that only about a tenth of its total area of over 90,000 square miles had been studied in detail geologically, and nearly a quarter of the area is still totally unexplored. By these publications in 1922-24 Stanley presented as complete a summary as possible of the geological and structural features of the whole of the region under British control, over 180,000 square miles. His presentation of this work, largely the result of his unaided efforts, attracted the keenest appreciation of the Pan-Pacific Science Congress held in Australia in August-September 1923, and this body expressed its high approval by special resolution urging on the authorities to supplement the excellent work that was being done. During the past year Stanley made a further journey into the great central ranges of Papua, and obtained important results which are as yet unpublished. He died at Adelaide at the end of December, 1924, leaving a widow and two young sons. All told, he had prepared about thirty reports on the geological features of Papua, of which a dozen, mostly those of more local economic interest, have not vet been printed. [W. N. B.]

REGIONS OF TENSION.

In many areas the Earth's crust has been subjected to compression manifesting itself in folding, cleavage, thrust-faults, and certain types of igneous activity. Such compression may prevail over an extensive region, or may be of a purely local character. In the former case it is usually attributed to the progressive contraction of the Earth's interior, although this has been disputed by some authorities. In the latter it is merely an incident in the development of more extended structures.

The results of compression have long been studied, but comparatively little attention has been given to the occurrence of tension in areas where it has left evidence of its existence in the form of joints, normal or slip-faults (occasionally replaced by monoclinal folds), or of dykes and other characteristic igneous phenomena. Tension is also probably accompanied by the stretching of plastic subcrustal material.

It must be remembered, however, that, if a period of compression is followed by one of tension, an original thrust-fault may operate as a slip-fault, and the total movement might place it in one or the other category. Similar anomalies will be met with where tension is followed by compression.

It is believed that joints and slip-faults are essentially similar. They are often closely associated, and there is every gradation between fractures without appreciable throw and those in which it is considerable.² A joint is the immediate result of simple tension. If, however, vertical forces also come into play, a slip-fault will result.

The existence of tension may be due, either to local conditions, or to forces acting on a widely extended area. We may thus distinguish between local and regional tension.

The most obvious cause of tension is the contraction of rocks which are not free to contract as a single unit, usually because they are attached at their under surface to other rocks that do not share in the contraction.

This contraction may be the result of cooling, which may

¹ C. E. Dutton, 'High Plateaus of Utah' U.S. Geol. & Geogr. Survey of the Rocky Mountain Region, 1880, chap. ii.

² A. Daubrée, 'Études Synthétiques de Géologie Expérimentale' Paris, 1879, pp. 329-33, and my personal observations in North Devon,

aug 1. 1925. p173 + aug 8ª 1925. p212. Sunnay.

part 2] ANNIVERSARY ADDRESS OF THE PRESIDENT. lxxxi

operate not only by way of thermal contraction, but by progressive crystallization. There can be little doubt that, in the earliest times of the consolidation of the Earth's crust, the cooling of its surface by radiation must have resulted in widespread tension followed by fissuring. This action must have ceased when the Earth's crust had been cooled to atmospheric temperature, and we cannot expect to find any trace of it now after the erosion and other changes to which the rocks have been since subjected; but it has been suggested that such fissures, subsequently filled in, are the origin of the rectilinear streaks visible on the surface of the moon. 1 As the Earth's surface is denuded the process of cooling penetrates ever farther into the Earth's crust, and fissuring, or, in other words, jointing, must take place.

There must be a limit of depth to this action,2 not only because the rate of cooling becomes inappreciable at considerable depths, but also because under great pressure the rocks appear, given the necessary time, to accommodate themselves to tension or other forces by flow rather than by fracture. The experiments of F. D. Adams & L. V. King 3 cannot be accepted as evidence to the contrary, as the time during which they lasted was represented by months instead of thousands or millions of years. Nevertheless, joints are found at depths of about 5000 feet (say, 1.6 kilometres), so that the pressure which prevails there is not sufficient to render rock-flow completely operative. Joints at such depths can, however, hardly be attributed to contraction on cooling, unless indeed it occurred before the superincumbent material was deposited. It would therefore seem that they must ordinarily be the result of

As sedimentary rocks are buried deeper and deeper by subsequent sedimentation, and subjected to an ever increasing load, they will contract vertically as the result of compression, as well as of the consequent elimination of water, and in certain rocks, such as carbonates and sulphates, of crystallization. These conditions will usually give rise to a horizontal lamellation. As the cover of later sedimentation increases, the temperature rises, and the resulting expansion increases the lateral pressure. Important consequences were attributed by Mellard Reade to this action; but I cannot

¹ H. Jeffreys, 'The Earth' Cambridge, 1924, pp. 146-48.

² V. O. Crosby, 'On the Absence of Joint-Structure at Great Depths, &c.' Geol. Mag. 1881, p. 417.

³ Journ. Geol. vol. xx (1912) pp. 97-98, 119-38.

believe that jointing is ever, as has been contended, caused by such pressure, though (needless to say) cleavage may be. When, however, accumulation ceases, and denudation supervenes, cooling, contraction, and jointing will result as already suggested.

Where igneous rocks consolidate at the surface, or at moderate depths, characteristic jointing takes place as the result of contraction on cooling. The prismatic jointing of lava-flows or sills is a familiar example.

Again, when rocks have become highly heated by the sun and are cooled by a sudden fall of rain, such as frequently occurs in the tropics in the afternoon, or by radiation at night, intense tension and explosive fracture may occur.¹

Similar results are, of course, obtained when rocks containing moisture are subjected to severe frost.

Contraction caused by desiccation produces results identical with those due to cooling. Not only is this seen in dried mud and soil, but the progress of denudation is ever bringing new rocks within range of the desiccating action of the atmosphere which is (of course) especially marked in dry climates, and this must frequently result in joints which extend deeper as the denudation proceeds.

The loss of volatile constituents by coal may well be one of the causes of the jointing or cleat which characterizes it.

Jointing may also be caused indirectly by expansion on heating. Thus the heating of a rock by the sun's rays may cause buckling and the development of a joint-plane approximately parallel to the surface. In the case of upstanding rocks the resulting jointing will be more or less rounded, and, if the exterior shell is removed by agencies of erosion, an 'elephant-back' rock will be left. In the case of a rock with a horizontal surface exposed in a river-bed when the river is low, the joints so formed will be horizontal. The heat of an intruded rock will also give rise to jointing parallel to the bounding surface of the intrusion, except when this is parallel to and near the Earth's surface, in which case the tension will be relieved by fractures at right angles instead of parallel to it.

¹ In former times it was customary to break up hard rocks by first heating the surface by lighting fires on them, and then pouring water over them.

² This principle is utilized in Southern India by lighting a line of fires on a flat surface of rock and gradually pushing it back, with the result that a slab several inches thick separates from the rock below.

The occurrences of tension which have been described rarely result in anything but simple jointing, without relative movement in the plane of fissuring.

Tension may also result from want of lateral support. There is a general tendency for joints to develop parallel to a cliff or escarpment-face, as it is cut back by erosion. These may ultimately result in falls of rock, or in landslips or faults. Where deep valleys are formed by erosion, faults are frequently found to occur parallel to them.

If regional tensional forces give rise to a fissure so wide and so deep that it involves a loss of support to the adjoining rocks, which slide down into it by a series of slip-faults, the fissure is termed a rift and the resulting valley a rift-valley.

Folding naturally tends to produce tension on the convex side of the curvature, and, if the tensile strength be exceeded, the rock will split with formation of jointing. This of course occurs mainly in anticlines, but it may also exist at the upper curve of a monocline and at both margins of a syncline. As a rule, the tension at the surface diminishes downwards until it becomes zero at a neutral surface, below which it is replaced by compression.

Where the convexity of the folding is directed downwards, as in a syncline, there should be compression above and tension below; but the pressure due to the depth would generally cause the rock to accommodate itself to the stresses affecting it by plastic yielding, rather than by fracture.

The extension in an anticline would rarely be considerable. If D° were the dip on the two sides, at the points where the curvature is reversed, and t were the thickness of the solid crust, or of so much of it as was involved in the folding, and if the neutral surface were halfway between its lower and its upper surface, and were unaltered in length, the total amount of stretching at the surface would be $\pi t D^{\circ}/180^{\circ}$. This would be independent of the width of the anticline at right angles to the strike. It assumes a simplicity of form which never actually exists, but gives some idea of the extension that takes place.

If the total thickness were 10 miles (16 kilometres) and the dip on either side 10°, the total stretching at the surface would be about 1.7 miles (2.8 km.). If the total width before the folding were 30 miles (48 km.), the increase would be more than 5 per cent., which is in excess of the amount to which rocks at normal temperatures and pressure are capable of being stretched without

fracture. Accordingly, jointing would result. As the rocks remain united at the neutral surface, it will take place at regular intervals, supposing that the rocks are uniform in composition and texture.

The total width of the joints would, however, not be equal to the total extension due to folding, for, after the rocks had been subjected to a tension beyond the limits of elasticity, and before fracture had taken place, they would have suffered a permanent elongation in the direction of the tension.¹

In these circumstances the individual joint-fissures would be so small that they could not of themselves give rise to slip-faulting, especially as the blocks separated by the joints are pressed together below the neutral surface.

On the other hand, if the dip on both sides of the anticline were 60°, the amount of the extension would be equal to the thickness of the folded beds, which would, however, as a rule be much less than in more gentle folds.

In any case, the fissures formed by folding would diminish rapidly in depth as the neutral surface is approached, and at the same time the weight of the superincumbent beds would give rise to elastic and plastic yielding which would tend to close them still more.

It must be remembered, too, that a great portion of every anticline is removed in the process of denudation. The theoretical height h of the centre of an anticline above its sides is given by the formula $h=W(1-\cos D^\circ)/2\sin D^\circ=\frac{1}{2}W\tan\frac{1}{2}D^\circ$, where W is the width at right angles to the strike of the anticline, after the folding. If the maximum dip on each side were 10° and the width of the anticline were 32 miles, the height would be about 3 miles (5 km.). If the dip were 60° and the width of the anticline 6 miles (10 km.), the height would be about $2 \cdot 3 \text{ miles } (3 \cdot 7 \text{ km.})$. In both cases a great portion of the rocks above the neutral surface would have been speedily eroded away, so that the fissures and clefts which remained would usually be comparatively small, although they would facilitate erosion at the apex of the anticline. Such folding would rarely give rise to extensive faulting, as the fissures would not be wide enough to admit of it.

In some cases, however, where the curvature is unusually great and the adhesion of successive strata involved in the anticline to

¹ Granite under tension would stretch 100 to 365 feet in 10 miles, 19 to 69 metres in 10 km., before it broke.

one another is comparatively small, the higher beds may split at or near the apex, and slip down the sides of the anticline as it rises. There is thus a fault-movement parallel to the stratification. This is the lag-fault of Prof. J. E. Marr.

In ordinary folding the fissures which are formed will rarely be filled with dykes, or afford a passage for volcanic extrusion, as there will usually be a zone of compression below them. In some cases powerful compression will result in igneous activity, but I do not propose to discuss them here, as they would be dealt with more appropriately when regions of compression were under consideration.

In regions of tension, on the other hand, superficial portions of the Earth's crust may be raised into anticlines or domes by the expansive or hydraulic force of magmas intruded below them either horizontally or vertically.

When the anticline or dome is formed by the action of an intruded magma, there will be no zone of compression and the covering rock will be wholly in a state of tension, which will frequently be increased by the expansion on heating of the rocks below, immediately in contact with the magma (see ante, p. lxxxii).

A dome thus formed—a laccolith in fact—is subject to both radial and tangential tension, and if not at too great a depth will develop radiating and circumferential fissures which afford passage for the magma. Thus are formed the cone-sheets, ring-dykes and faults, and other phenomena incidental to such a centre of eruption, which are described in the invaluable Geological Survey memoirs on the Tertiary igneous rocks of the West of Scotland.

If in this, or in any other way, a centre of volcanic activity comes into existence in a region of tension, the accumulation of material above and the creation of a deficiency below may result in the central portion sinking into the magma below and forming a cauldron-subsidence.

In the case of plutonic rocks that are intruded in the form of a laccolith, the central sinking which follows the intrusion often gives to the mass a synclinal character, as at Sudbury in Ontario, in the Boschveldt of South Africa, and in the larger plutonic intrusions of Skye.

In Arran, on the other hand, the granite is surrounded by a circular zone of schists dipping outwards, and these by concentric faulting which separates them from the Old Red Sandstone. The granite appears to have occupied a laccolith, and the centre has

been raised in excess of the curvature, with the formation of a circular fault having a central upthrow.

Similar relations occur when the structures accompanying intrusions are longitudinal instead of circular, as in trough-faults associated with igneous activity.¹

Tension may also occur as a reaction against compression when the forces causing the latter have ceased to operate. In the great periods of compression the faults are overthrusts, with a strike parallel to that of the folding; but they are frequently followed by normal faults with the same strike. This occurs in connexion with the Hercynian folding in North Devon, and apparently also in that of South Wales. For the same reason, in Scotland the Caledonian folding was followed by the intrusion of north-east and south-west dykes, and the Hercynian folding by east-and-west dykes. Doubtless in some cases a backward slip may occur, as already suggested, in the thrust-planes themselves.

Where such tension occurs during a period of reaction after folding under compression, it is frequently of a regional character, and the resulting joints, faults, and dykes extend over a wide area parallel to the folding.

Tension of a regional character may also be due to external causes, and represent the net effect of gravitational forces. What these are, and how they operate, will be considered later. Such tension is generally distinguished by its extent and general uniformity in character and direction, except where it is influenced by local conditions. At the same time, the joints, faults, and dykes produced by the tension are either not parallel to important neighbouring folds, or date from a period so much posterior to them that they cannot be regarded as the result of a reaction following the compression that gave rise to the folding.

If tension occurs only in one direction, the strike of the resulting joints, faults, or dykes will obviously be at least approximately at right angles to it. If, however, there is an appreciable tension in all directions, but it is at a maximum in one and at a

¹ Prof. W. C. Brögger attributes the downward sag round a centre of basic eruption to the excess of density of the plug of rock left in the vent, Nyt Mag. for Naturvidensk. vol. xxviii (1884) p. 389, etc. Sometimes a wide dyke appears to replace the 'country-rock' instead of occupying an opened joint or fault. This may be explained by the supposition that two narrow parallel dykes came into existence in close proximity to one another, and that the intervening rock was either pushed upwards by the magma, or sank down through it; see M. P. Billings, Journ. Geol. vol. xxxiii (1925) pp. 140–50.

minimum in another (which will be at right angles to the first), there will be two conjugate series of joints at right angles to one another. For the first splitting will be perpendicular to the direction of maximum tension, and this will release all the components parallel to that direction; so the only tension remaining will be parallel to what was the direction of minimum tension, and the splitting that it produces will accordingly be at right angles to that which had been produced by the direction of maximum tension. This is in accordance with the principle of least work: for, if the second splitting were oblique to the first, the surface along which the splitting took place would be greater.

If the tension in all directions were approximately the same, hexagonal jointing would result, as it does from the cooling of lava-flows or sills and from the drying of the gypsum of the Paris Basin.¹

In determining the relative age of two conjugate sets of faults, it is important to make certain that the members of one set are actually shifted by those of the other, by establishing the identity of the different portions of the faults supposed to be shifted. In default of this, the fact that the individual faults of one set come to an end on meeting those of another set tends to prove that the former are younger, not older, than the latter.²

In cases where the tension is mainly due to contraction, and would in that respect be equal in all directions, the existence in addition of regional or other external causes of tension will naturally determine the direction in which fissuring will take place.

Sometimes there are two or more series of joints, faults, or dykes, each consisting of two sets of conjugate joints, faults, or dykes at right angles to one another, while those of the different series are oblique to one another. These would seem to represent two or more periods of tension, having different directions.³

¹ J. B. Jukes, 'Geology' 3rd ed. (1872) p. 180; W. W. Watts, Geol. Mag. 1881, p. 526.

² A. Daubrée, 'Études Synthétiques de Géologie Expérimentale' 1879, pp. 337-38, 340.

³ Thus Samuel Houghton states that, in Waterford, one set of conjugate faults strikes about 57½° east and 31° west of north, another about 32° east and 60° west of north, and a third 4½° east of north and 84° west of north. The three sets, therefore, intersect at about 30°. He believed that this relation was determined by mechanical principles. See Phil. Trans. vol. cxlviii (1858) pp. 333–48 & vol. cliv (1864) pp. 393–442; also Journ. Geol. Soc. Ireland, vol. ii (1871) p. 163.

A simple explanation would apply where the jointing of two successive beds is not in identical directions. We may suppose that, on account of its physical characters, the jointing of one bed took place before that of the other. The jointing (cleat) in coal and that in the rocks in which it is intercalated is an example. Not only the period of jointing, but also the distance apart of the joints, may be different in different beds. The latter appears to depend on the thickness of the bed and its tensile strength, as well as its tendency to contract from loss of volatile constituents (as in the case of coal) or from crystallization (as in limestones).

Evidence of regional tension in an area characterized by igneous activity will frequently be afforded by numerous parallel dykes (mostly basic in composition) which follow the direction of the jointing at right angles to the main direction of tension, and in some cases a smaller number of conjugate dykes at approximately right angles to the former. The total thickness of parallel dykes will furnish a measure of the extension at right angles to them, except so far as any of them are formed by replacement of the country-rock. See note on p. lxxxvi.

Daubrée made a number of experiments on the action of torsion and compression on the fracturing of rocks.\(^1\) He showed that the latter produced conjugate fractures, making equal angles with the direction of pressure and nearly at right angles to one another. These oblique fractures would be represented in Nature (if at all) by thrust-faults, and do not concern us here. Torsion also gave rise to similarly related conjugate fissures, and he regarded the existence of torsion as the true explanation of the frequent occurrence of conjugate faults nearly at right angles to each other.

There is no reason to doubt that torsion does occur in the Earth's crust. It is obvious that, when forces and the resistances to them vary from point to point, couples must exist which exercise torsion on the rocks. These should result both in compression and in tension, and, of the conjugate fractures that result, some would be in the nature of thrust-faults and others of slip-faults.

A simple case is that described by A. E. Fall.² Here a foundation of hard rocks was overlain by comparatively weak limestone and sandstone. A north-and-south fault appears to have formed in the hard beds, in which the eastern side had a relative

^{1 &#}x27;Études Synthétiques de Géologie Expérimentale '1879, pp. 300-78.

² Prof. Papers U.S. Geol. Surv. No. 12 (1920) pp. 77-80.

movement to the north and the western to the south. This caused torsion in the sandstone, resulting in compression in a north-east and south-west direction, and tension in a north-west and southeast direction. At right angles to the latter were narrow fissures arranged in echelon above the concealed fault. The former merely resulted in local compression of the sandstone.

Another case is a local incident of folding due to compression. If the force producing this folding or the resistance to it vary at different points along the strike, the result will be either oblique folding which does not concern us here, or faults separating areas in which there is a difference in the folding. These differential faults are the 'décrochements horizontaux' and 'Blätter' of Continental authors, and the tear-faults of Marr. They are usually distinguished by the fact that the fault-plane is approximately vertical, and at right angles to the strike of the folding. The throw of the fault frequently varies at different points, and the downthrow may be sometimes on one side and sometimes on the other, and at an intervening point the strata will appear to have rotated on a horizontal axis at right angles to the fault.

Daubrée's claim, that all occurrences of two conjugate directions of jointing or faulting approximately at right angles to each other are the result of torsion, cannot be supported. As I have shown, this relation should occur in all cases where there has been general tension, but with a maximum and minimum direction.

I now propose to make a brief survey of areas in which regional tension appears to have existed. I shall then endeavour to ascertain what evidence these afford as to the conditions under which the tension existed, and the consequences that followed from it. I shall, as a rule, confine my remarks to tension of post-Permian date. It is, however, obvious that, in many cases, it is impossible to determine the point in geological history at which evidences of tension originated. Post-Permian tension appears in some cases at least to have had its beginning in Permian times, and it would be better, perhaps, to define the period covered as post-Hercynian, remembering that the Hercynian movements in the British Isles appear to have taken place on the confines between the Carboniferous and the Permian Systems.

I shall commence with the south-western peninsula of Great Britain, with which I am personally most familiar. This district, which comprises the counties of Cornwall and Devon and West Somerset, has suffered a succession of earth-movements of considerable magnitude.

Following on the deposition of a great thickness of sediments in Devonian and Carboniferous times, accompanied by gentle undulatory movements with which I am not now concerned, the Hercynian epoch of crustal instability was signalized by the development of strong pressure from the south or south-southeast which threw the strata into numerous overfolds with an eastand-west or east-north-east and west-south-west strike, and ultimately gave rise to well-marked slaty cleavage and to overthrusts, while great granite-magmas were intruded from the same direction. The reaction which followed gave rise to normal faulting, with approximately the same strike. Somewhat later, an east-and-west pressure, at right angles, therefore, to the previous compression, gave rise to pleating in the already highly cleaved slate, and, as I understand from Dr. A. Brammall, to north-and-south flexures in the still incompletely consolidated granite. A second reaction appears to be indicated by north-and-south and north-east and south-west normal faulting, in which the downthrow is to the east or south-east, with (in some cases, it would seem) a lateral movement to the north or north-east, on the east or south-east side.

All these movements appear to have taken place before the Permian rocks of Devon and West Somerset were laid down.

Traversing these structures are numerous north-north-west and south-south-east faults approximately parallel to one another, though in places a group of them appear to have been subsequently rotated together through a small angle.

The hade is almost invariably to the west-south-west, at angles with the horizontal varying from 45° to 85°. In practically every case the outcrop is moved towards the north-north-west on the west-south-west side, perhaps only a few inches, but it is sometimes as much as several hundred yards. At first sight, it might be thought that, as the dip of the cleavage and of the strata (except occasionally in folds) is southward, the movement of the outcrop might be accounted for simply by a downthrow on the west-south-west; but the shifting of the folds shows that there is a considerable horizontal component towards the north-north-west. This is confirmed by the fact that, wherever slickensides can be observed, they dip at a low angle (15° to 30°) north-north-west-wards in the fault-plane.

It is possible that the first movement may have been directly

down the fault-plane and that there was a second movement in a north-north-westerly direction.

There is a considerable amount of jointing parallel to these faults, without any perceptible throw.

Finally, there appears to have been a general tilt to the west, as the axes of the major and minor folds, which presumably were originally approximately horizontal, now incline as a rule downwards in that direction at a low angle, say 5° to 15°. There seems to have been at the same time fissuring with a strike from north to south, or a very little west of north to a little east of south. These fissures, which are either filled with calcite, or remain as joints, dip eastwards at about 60°.

It is, I think, clear that the north-west-and-south-east faults were, as a rule, long posterior to the Hercynian folding and the other movements that I have described as accompanying or immediately succeeding it. They cut the stratification-cleavage and folds so sharply that these must have been in much the same state then as they are now, whereas the north-west-and-south-east faults are responsible for considerable deflexion of the stratification and cleavage. The faults also shift calcite- and quartz-veins which are roughly parallel to the cleavage, but were posterior to the folding. The facts that they cut the folds obliquely, and that the hade is often considerable, are additional indications that they are not differential or tear-faults, contemporaneous with the folding.

Their late date is also proved by the circumstance that they cut the Trias and Lias where, as in West Somerset, these are present; and that slickensides are still well marked on the calcite-lining of fault-fissures, where these are exposed to the solvent action of rain-water. Finally, aragonite is often met with filling joints in the limestone, so that there must have been a circulation of hot water, an indication of recent endogene activity: for aragonite only forms from hot water, and is unstable at ordinary temperatures.

Local faulting is also occasionally seen parallel to the Bristol Channel and its tributary valleys. These were excavated in probably Permian times, and afterwards partly or wholly filled with Triassic or Liassic deposits, now more or less re-excavated. The downthrow is usually towards the Bristol Channel, or the valley, as the case may be.

The same series of faults appears to extend all through North Deven and North Cornwall. Everywhere the lodes which occupy east-and-west fractures parallel to the general strike of the country are moved to the north-west on the south-west side of the north-west-and-south-east faults. Hence the miners' rule that, when a lode is intersected by such a fault, it is heaved to the right. This is, of course, true, whether the fault is approached from the east, or from the west.

Faults presenting the same characters occur on the southern coast of Cornwall on a still larger scale. One runs north-westwards from Cawsand Bay, and another in the same direction from near Port Wrinkle. Each seems to cause a heave to the north-west on the south-west side of about 4 miles. Similar but smaller faults are met with on the southern coast farther west; the Lizard mass appears, however, to have resisted the conditions which elsewhere resulted in this faulting.

In Cornwall these north-west-and-south-east faults are usually referred to the Tertiary Era.¹

It is noteworthy that the coast does not appear to be determined by the strike of Hercynian folding or by that of the different types of faulting or folding which have been described: for instance, the hard resistant rocks known as the Hangman Grits, which form a conspicuous hill-ridge, come to an abrupt end at the 'Little Hangman' against a fault which should shift them seawards a short distance to the north-west; but there is no evidence of their continuation, not even a submarine ridge. The shore-line appears to be primarily the result of the configuration of the surface resulting from the subaërial erosion to which the country appears to have been subjected after the Hercynian folding, modified of course by subsequent isostatic adjustments and other movements.

The latest jointing affecting the granitic and other rocks from the Scilly Islands to Dartmoor has an average direction from a little west of north to a little east of south,² but it varies somewhat with the general strike of the country, tending to be roughly at right angles to it.

East of the south-western peninsula the passage from the Palæozoic rocks on the west to the Mesozoic rocks on the east is determined or assisted by parallel faults with a north-and-south

¹ 'The Geology of Falmouth, Truro, &c.' Explan. of Sheet 352, Mem. Geol. Surv. 1906, p. 9.

² H. T. De la Beche, 'Report on the Geology of Cornwall, Devon, & Somerset' 1839, pp. 270-75; see also the recent Memoirs of the Geological Survey relating to Sheets 337 (p. 71), 347, 351 & 358, 352, 357, & 360; and a communication from Dr. A. Brammall.

strike and downthrow on the east, beyond which in Southern England is a region of east-and-west folding and north-and-south compression in Tertiary times, combined, however, it would seem, with east-and-west tension.

North of the Bristol Channel, in the south of Pembrokeshire, there are numerous north-north-west and south-south-east faults that present the greatest similarity to those with the same strike on its southern shores. They invariably hade west-south-westwards, and the rocks are shifted to the north-north-west on the west-south-west side. As this movement is not affected by the dip of the beds, the heave of the fault must be mainly lateral, a conclusion which is confirmed by the horizontal or only slightly inclined slickensides.

There are also a number of north-north-east and south-south-west faults in which, in the majority of cases, there is an apparent lateral movement to the north-north-east on the east-south-east side towards which the faults hade.

Mr. E. E. L. Dixon, of H.M. Geological Survey, who has given an instructive account of the structure of the district in the Survey Memoirs, includes both series under the term cross-faults, and considers that, while they were undoubtedly posterior to the Hercynian folding, they were not much later, and were part of the same general crustal disturbances. The existence of two directions making about equal angles with the direction of the Hercynian thrust suggests the fractures that Daubrée found to result from the application of compression (ante, p. lxxxviii), but fractures so produced should be thrust-faults, not slip-faults. Mr. Dixon's chief argument for the Hercynian origin of the north-north-west and north-north-east faults is that, as they approach the outcrop of the Hercynian thrust-faults, they appear to bend round and join the latter. At the same time, although they traverse some of the Hercynian folds, they fail to pass the Ridgway anticline. However, the fact that their development was affected by the Hercynian structures, to which they are admittedly posterior, does not show that they succeeded these latter after only a short interval of time. It is to be expected that the course and character of faults should be affected by pre-existing structures. In Bullslaughter Bay fissures due to north-north-east faulting are filled with Triassic sediments; but that does not prove that they were pre-Triassic, any more than the fact that pipes in the Chalk are filled with Tertiary sediments proves that they are pre-Tertiary. Even if the north-north-east faults are pre-Triassic, it does not follow that the north-north-west faults, which so closely resemble those south of the Bristol Channel, are pre-Triassic likewise.

There seems no definite system of oblique or dip-faults north of Carmarthen Bay; but, in the counties of Glamorgan and Monmouth, north-north-west faults are a very marked feature of the structure. They differ, however, in some respects from those of South Pembrokeshire. There is no clear evidence of lateral movements, and although the hade and apparent downthrow are preponderatingly to the west-south-west, there are areas in which easterly downthrows also occur, as in the neighbourhood of Neath (east of Sheets 229 & 246, and Sheets 230 & 247 of the Geological Survey map), where the faults are nearly due north and south and at right angles to the folds. However, the easterly downthrow does not extend far either to the north or to the south of the maximum development. In Monmouthshire the north-north-west faults are accompanied by well-marked conjugate east-north-east faults.

The folding in South Wales is, as has been stated, mainly of Hercynian age, although small movements of this character seem to have occurred later. The north-north-west faulting is admittedly posterior to the Hercynian folding. It frequently cuts the Triassic and Liassic rocks, and is therefore presumably of Tertiary age; but it can be shown that many of the faults have a larger throw in the Carboniferous than in the Trias, so that these (though post-Hercynian in any case) must have commenced in Permian times.²

As in Somerset, post-Triassic faults occur on the margin of pre-Triassic valleys which are or have been filled with Triassic or later sediments.

There appears to be no means of determining the age of the faults in Central Wales, except that they are of course later than the older Palæozoic rocks in which they occur, nor do they appear to have any prevailing direction. However, on the Welsh border the great Malvern Fault, which brings the Trias down against the Pre-Cambrian and Palæozoic rocks, has a definite eastward hade, and affords evidence of decided east-and-west tension in post-

¹ See Explan. of Sheet 247, Mem. Geol. Surv. 1907, pp. 97-98.

² Sir Aubrey Strahan, Geol. Mag. 1899, pp. 113-14; Explan. of Sheet 247, Mem. Geol. Surv. 1907, pp. 97-98 & Explan. of Sheet 248, 2nd ed. (1917) pp. 2, 77, 78, 105-6, 110-19.

Triassic times. Beyond it in Central England it is unusual to meet with any but slip-faults. Their most frequent strike is still north-west and south-east, though the conjugate north-east and south-west direction is not uncommon. Other directions of strike also occur; but, in many cases, there is no means of determining their exact age. The presence of north-east and south-west tension in Kainozoic times is, however, demonstrated by the west-north-west dykes of Butterton and Swynnerton in North Stafford-shire 1 and Grinshill and Acton Reynald in Shropshire. 2 The former is a nepheline-olivine-dolerite and the latter an olivine-dolerite, and both are undoubtedly representatives of Tertiary igneous activity.

It may be remarked that dykes generally afford a less equivocal indication of the direction of maximum tension, as conjugate dykes are comparatively less common than conjugate joints and faults.

In North Wales, also, there is evidence of similar tension. In Bardsey Island, Dr. C. A. Matley has described several dykes of olivine-dolerite with a north-west and south-east strike, which have Tertiary affinities.³ Similar dykes occur in the Lleyn Peninsula, and Mr. David Williams has also described them at Marchlyn and Bwlch y Cywion between Nant Ffrancon and the Pass of Llanberis.⁴

Prof. W. G. Fearnsides remarks 5:

Of the details of Tertiary faulting in Wales we know but little, and are quite unable to distinguish its effects from those of the post-Triassic or even the post-Carboniferous earth-movements. Like them, it generally follows older fault-lines which had survived from the mountain-building of the Devonian. Possibly the clean-cut structure-lines which range from north-west to southeast across the Cambrian rocks of Merioneth and Caernarvonshire, which cut alike all beds, intrusions, cleavage, and thrust-planes with but little displacement, may be Tertiary, but, pending the finding of less weathered examples of the little basic dykes which occasionally follow these structure-lines, we cannot tell.'

¹ W. Gibson & J. S. Flett, 'North Staffordshire Coalfields' Mem. Geol. Surv. 1905, pp. 190-97; W. W. Watts, Proc. Geol. Assoc. vol. xix (1905) pp. 173-80.

² R. W. Pocock, Explan. of Sheet 138, Mem. Geol. Surv. 1925, pp. 60-64.

³ Q. J. G. S. vol. lxix (1913) p. 525.

⁴ Proc. Liverpool Geol. Soc. vol. xiv (1924) pp. 32-47.

^{5 &#}x27;Geology in the Field' Geol. Assoc. 1910, p. 820.

However, I understand from a letter recently received from him that such evidence has been forthcoming. In Anglesey, Dr. E. Greenly describes the latest faulting as having a north-northwest and south-south-east strike, and there are dykes of olivine-dolerite, believed to be of Tertiary age, with a similar direction.

In the North-East of Wales the later faulting, which is of considerable importance, is predominantly north-west and south-east; but it is modified locally by the pre-existing structures of the rocks which, it is claimed by Mr. C. B. Wedd, are the result of torsional forces. These faults are in some instances demonstrably post-Triassic, and are probably so in practically all cases. In the Wirral Peninsula between the Dee and the Mersey, on the other hand, the faults are as a rule nearly north and south. They traverse the Triassic rocks.

In Lancashire and in the North of England generally the dominant direction of the faulting is again north-west and south-east, conspicuously represented by the Pennine and Craven Faults with a downthrow to the south-west. Conjugate north-east and south-west faults also occur. Much of the movement appears to have taken place in early post-Hercynian times, though it was continued later in the Mesozoic or Kainozoic Eras. The probable existence of north-north-east and south-south-west tension in the latter is shown by the strike of the Cleveland and other dykes of typically Tertiary facies which strike west-north-west and southeast, and cut Jurassic rocks. There can be little doubt that they are, in fact, of Tertiary age.

In this area the predominant direction of the cleat in the coal and of the jointing in the Carboniferous Limestone is also northwest and south-east.

The characters of the joints, faults, and dykes of the North of England are well described by Prof. P. F. Kendall & Mr. H. E. Wroot in their 'Geology of Yorkshire' 1924, pp. 130-31, 234-51,1

In the Isle of Man the predominating direction of the faults is north-west and south-east, and this is also that of the later dykes which are apparently of Tertiary age.

In the South of Scotland the frequent occurrence of north-west and south-east Tertiary dykes shows that there, too, a predominating north-east and south-west tension prevailed in Kainozoic times.

¹ See also E. Hull, Q. J. G. S. vol. xxiv (1868) pp. 319-32.

Farther north, in the Inner Hebrides and on the adjoining mainland, the north-west and south-east Tertiary dykes become very numerous. Igneous activity commenced here with great outflows of basic lavas from volcanic vents, or from linear or circular fissures. These were followed by important more or less horizontal deep-seated intrusions, those of more basic character being, as a rule, prior in time. They probably were originally of the nature of laccoliths, but, as the result of subsequent sinking, they sometimes assumed a synclinal structure, or developed into cauldron-subsidences.

These intrusions were accompanied and followed by the northwest and south-east dykes in approximate parallelism. In the neighbourhood of a massive intrusion, however, they converge towards it as if to a node. This is obviously due to the fact that it is a point of weakness in the Earth's crust, and that, if the fractures pass through it, less force is required than if they continued on their way at right angles to the general tension.

These phenomena and others described in the Memoirs of the Geological Survey are quite consistent with the supposition that all the igneous activity of the region is to be attributed ultimately to the extended prevalence of crustal tension, modified by local circumstances, especially the physical properties and structure of the rocks, which, as we know, had been subjected to powerful forces during both pre-Torridonian and Caledonian times, and had been profoundly affected by them. There is nothing to show that any important compression was associated with this period of igneous activity. It was magmatic pressure and movements that were responsible for such folding as occurred, whether the elevation of laccoliths or local depressions following on intrusions or eruptions.

The north-west and south-east dykes are especially numerous in Mull, Muck, Eigg, and Skye. On the south-eastern coast of the first-mentioned island their total thickness amounts to more than 2500 feet (800 metres). On the north-western coast they represent 817 feet in a mile and a quarter (250 metres in 2 km.). Their intrusion must consequently have been accompanied by considerable stretching of the crust. They are accompanied by numerous slipfaults, the majority of which have the same strike, but others have a more northerly direction, and some are due north and south. They seem to be, on the whole, later than the dykes. Conjugate dykes and faults following a north-east and south-west direction also occur, and may be of slightly later date.

VOL. LXXXI.

In Skye similar dykes occur, with a strike averaging between north-west and north-north-west. Here the basalt-flows are repeatedly fractured by faults with a north-west and south-east strike and a downthrow to the north-east, while the individual blocks are tilted to the south-west, either for want of support on that side, or because there was a flow beneath them in the opposite direction, which dragged their bases with it. This appears, in fact, to have been the direction of the flow of the magmas which formed the major intrusions.

In the west of Sutherland there are numerous north-west and south-east dykes of a character very similar to that of those farther south, but, instead of being of Tertiary age, they are pre-Torridonian. Cumulatively, they, also, must represent a very considerable extension of the Earth's crust at the time when they were intruded. The rocks are here traversed by faults of a much later period predominantly north-east and south-west, indicating tension directed to the north-west. These may well be of Tertiary age, but no evidence is available on this point.

There is some north-and-south normal faulting in the Shetlands, Orkneys, and Caithness; but, on the north-western shores of the Moray Firth, the principal faulting is parallel to the shore-line, with a downthrow to the south-east which brings down and preserves near the coast Mesozoic rocks that once doubtless extended farther north-westwards, and that probably still exist below the waters of the Firth. On the south side of the Firth, Triassic rocks are brought down in a similar manner by east-and-west faults. On the margins of the Firths of Tay and Forth there are indications of a similar downthrow towards the Firths, which probably represent drowned valleys of erosion, and the faulting on their margin would seem to be due to purely local conditions. There appears to be little evidence of tension towards the North Sea on the east coast of either Scotland or England.

In Ireland, in Eastern Ulster there is an area of volcanic activity similar to that of the West of Scotland. Besides the widespread lava-flows (mostly basalts) and the granitic intrusions, there are a number of dolerite-dykes, which are found not only in the east, but as far west as the coast of Donegal. They maintain the same characteristic north-west and south-east strike as in Great Britain.²

¹ They are also reported from Lewis.

² Explanatory memoirs and maps, Geol. Surv. Ireland, especially the memoir on North-West & Central Donegal, chap. ix, Sheet 3, &c. (1891) pp. 95-98.

West-north-west and north-west basic dykes occur on the north coast of Mayo in the Survey sheets 39 and 40, which W. A. Traill described as 'of post-Carboniferous origin and in all probability of much later date, even of Tertiary age.' Similar dykes are found in Sligo on the western shore of Killala Bay and the southern shore of Sligo Bay. Mr. W. B. Wright believes that these dyke-swarms are associated with a Tertiary granite east of Lough Easky.

There are in Ireland two main directions of faulting, which strike roughly north-west and south-east, and north-east and south-west respectively; but evidence even of their post-Permian or post-Hereynian age is not always forthcoming.

However, on the north-east there is a region of north-west and south-east faulting evidently related to the post-Hercynian faults of the Isle of Man and Northern England, and much of it is doubtless of Tertiary age. On the north coast of Eastern Ulster, east-and-west faults occur, throwing the Tertiary basalt-flows down towards the sea. These faults, also, must be of Tertiary age.

In some parts of Western Ulster and North-West Connaught the prevailing strike of the faulting is north-east and south-west; and, in Northern Donegal, a north-west and south-east Tertiary dyke is stated to be shifted by a fault, presumably north-east and south-west in direction (op. cit. p. 97). West of Lough Conn and in Kerry groups of faults occur similar in strike and movement to the north-west-and-south-east faults in Devon and Cornwall. In the South of Ireland generally, the strike of the faulting which affects the Hercynian folds varies from north-north-west to nearly north and south, and there is an important joint-system with similar directions (see p. lxxxvii, note 3).

It may also be noted that there appears to be a tendency for local faulting to occur parallel to the margins of the wider inlets of the sea in the West of Ireland, similar to that parallel to the firths in the East of Scotland.

In Britanny the Palæozoic rocks which were folded in the course of the Hercynian crustal movements are fractured first, as in Devon, by strike-faults, and subsequently by north-west-and-south-east faults. Prof. Charles Barrois, to whom I am indebted for this information, believes that these latter owe their origin to torsion, and that they date from the close of the Hercynian movement, although there have been in some cases subsequent movements on the same fault-planes which may be of Tertiary

age. In any case, the fault-system of Britanny shows a remarkable resemblance to those of the south-western peninsula of England and of South Wales.

Jointing occurs with a strike somewhat west of north, but the most striking evidence of tension is afforded by numerous basic dykes. They occur in somewhat radiating sheaves in a wide tract on the south of the bays of St. Brieuc, St. Malo, and St. Michel. Their strike varies considerably, but the north-north-west and south-south-east and north-and-south directions are most characteristic. They intersect the Hercynian folds, but Prof. Barrois, who describes them as ophitic diabases, believes them to be of Palæozoic age. 1

North-west and south-east faults extend down the West of France parallel to the coast. They also occur in the Boulonnais, in Devonian rocks that have been thrust over Carboniferous beds, which, however, curiously enough, are apparently unaffected by the faulting. It resembles in some respects the faulting observed in North Devon, but its age is uncertain.

In the North-East of France the faulting is mainly north-east and south-west; but, farther south in the neighbourhood of the rift-valley of the Rhine between Basel and Mainz, the strike becomes parallel to it, and has a north-north-easterly direction. Faults with a similar strike occur also east of the Rhine. In each case the downthrow is towards the valley. It has been contended, however, by W. Salomon,² that the valley is bounded by thrust-faults and is the result of compression. This, however, is not generally accepted.³ O. M. Reis, after a careful consideration of the subject, comes to the conclusion ⁴ that this and certain rift-valleys (Gräben) in France, including the parallel valley of the Saône, are due not to compression but to tension.

In the North-East of Belgium and the South-East of Holland borings have revealed the existence of faulting, probably of Tertiary age, and having, it would seem, a north-and-south or north-west-and-south-east strike. The downthrow appears to be, as a rule, eastward. I am indebted to Prof. Max. Lohest and Prof. G. A. F. Molengraaff for information on the subject.

¹ 'Le Bassin du Ménez-Belair' Ann. Soc. Géol. Nord, vol. xxii (1894) pp. 181-96; see especially pl. iii.

² Zeitschr. Deutsch. Geol. Gesellsch. vol. lv (1904) pp. 403-18.

³ E. Kayser, 'Allgemeine Geologie' 7th & 8th ed. vol. i (1923) p. 271.

⁴ Geognostische Jahreshefte, 27th year (1914) Munich, 1915, pp. 249-78.

Prof. W. C. Brögger has studied in detail the strike of the faults, joints, and basic dykes of the Langesund area. The strata strike north-north-west and south-south-east, and dip east-northeastwards. There are two chief sets of conjugate faults, one striking north and south and east and west, and the other north-north-west and south-south-east and east-north-east and west-south-west.1 The chief directions of jointing are said to be north and south and north-north-east and south-south-west. The dykes strike. with few exceptions, either north and south, or north-north-west and south-south-east. They usually dip steeply westwards. Brögger divides them into an older (proterobase) and a younger (diabase) group. The former are of Downtonian age, while the latter may possibly be of Tertiary age. Out of eight dykes which a microscopic examination showed to belong to the younger group, five had a north-and-south strike, two a north-north-west-andsouth-east strike, and one a west-north-west-and-east-south-east strike. Of the two supposed older dykes one had a north-andsouth and one a north-north-westerly strike.2

The adjoining Christianiasund Fiord appears to be a rift-valley. It has a north-north-east and south-south-west direction. It is probably Downtonian, or but little later.

I now propose to consider the conclusions which we can deduce from the distribution and direction of the jointing, the slipfaulting, and the dykes of Western Europe that are of post-Hercynian date. All are due to tension, producing stretching, fracture, and separation, and together they imply relative movement, or drift, in the rocks with which they are associated.

The most prevalent strike of these fractures in the British Isles and Western France is from north-north-west to south-south-east, implying a drift from east-north-east to west-south-west, or vice versa. As a rule there is nothing to show which it is; even the direction of the bade is not decisive, as adjoining faults frequently hade in opposite directions. However, in the Devon-Cornwall peninsula there appears to be a general downward slip to the south-west, modified, it would seem, later by a movement towards the north-west. In Skye the faults posterior to the igneous activity appear to show a similar change in the direction of the tension. In

¹ W. C. Brögger, 'Spaltenverwerfung in der Gegend von Langesund' Nyt Mag. for Naturvidensk. vol. xxviii (1884) pp. 338-39.

² Ibid. pp. 375-84.

the north-west of Connaught, of Ulster, and of Sutherland the faults appear to strike as a rule north-east and south-west, implying the presence of a drift to the north-west, but in Western Ulster, and in Mayo, this appears to have been preceded by an earlier tension directed towards the south-west or south-south-west, indicated by the north-west-and-south-east or west-north-west-and-east-south-east basic dykes.

Closely connected with the drift of the surface-blocks must be the stretching of the presumably plastic zone beneath. Indeed, it would seem that it is this stretching or slow flow which is the immediate cause of the minor fissuring of the crustal rocks. The blocks which are thus formed are then so disposed relatively to one another as to cover as far as possible the extended space. This may happen in two ways:—

In the south-western peninsula of England and other localities the fault-fractures had originally considerable hade, usually directed to the region of weakness, and the extension took place by the downward slip of the block on the upper side of each fault.

In Skye and elsewhere the hade of the fissures seems originally to have been practically vertical; but the blocks between the faults were subsequently inclined, so that the beds which were formerly nearly horizontal now dip in a direction opposite to the faults. In this case the covering of the extended area is effected by the tilting of the blocks. It is probable that in such cases the underlying magma has, as already suggested, flowed in the direction of the hade of the faults.

The volcanic activity in the West of Scotland and in the North-East of Ireland commenced, on the evidence of plant-remains, early in the Eocene, and may have continued for a great portion of that period. The faulting which has been described must have been of still later date. It is, indeed, impossible to fix any limit to the continuance of the tension. How far it was present in Mesozoic times we cannot say with certainty, but it apparently had a beginning in the Permian; while the pre-Torridonian dykes of the North-West of Scotland suggest that something of the sort may have existed at a much earlier date.

The drift towards the west (south-west or north-west) in Western Europe seems to have been widespread, though greater in some regions than in others, but everywhere east-and-west distances appear to have been increased.

We are not in a position to estimate the total amount of this

extension. It could only be calculated if we knew the width of each joint, the hade of each fault-plane, the direction and amount of the movement in it, and the thickness of each dyke. It does not, however, seem likely that the total relative change of distance between Central Europe and Western Ireland has exceeded say 6 to 12 miles (10 or 20 kilometres) since Triassic times.

The true significance of this drift becomes evident on examination of a depth-chart of the North Atlantic. It is at once seen that the approximately north-west and south-east strike of different forms of fracture that is so prevalent in the British Isles and Western France is related to the ocean-deep of which the northeastern boundary runs roughly south-east and north-west, parallel to the French coast of the Bay of Biscay, out into the open Atlantic; and that the north-east-and-south-west strike which is found in the north-west is apparently similarly related to the edge of the trough that extends from south-west to north-east beyond the Hebrides. The drifts to the south-west and north-west seem to be towards these abysmal regions of deep water, the crustal blocks being carried forward by the flow of the plastic region beneath. The formation or widening of these deeps cannot have greatly preceded the drift towards them, which seems to have culminated in Tertiary times. From what has been stated, there would seem to be reason to suppose that the development of the oceanic deep on the north-west of the British Isles was of a later date than that on the south-west.

Formerly the existence of these troughs was explained very simply by the hypothesis of the foundering of the ocean-bed, as a result of a deep-seated local contraction due to cooling or crystallization, or change from one crystalline structure to another.

The records of the transmission of earthquake vibrations through the Earth show, however, a remarkable similarity in the mechanical characters at equal depths in different parts of the Earth, so that it is extremely unlikely that one area would contract so much more than another in its neighbourhood. In any case, most of the changes of this character that were possible must have occurred long ago, in an earlier period of the Earth's existence. It is more reasonable to suppose that these troughs are, as contended by Wegener, themselves the result of the drifting apart of adjoining portions of the Earth's crust.

The doctrine of the balance or 'isostasy' of different areas of the Earth's surface, which now seems to be firmly established, requires that the continents should be composed of lighter materials than the floor of the deep sea. The former consist mainly of granite (including the foliated granite more usually described as granitoid gneiss) and of sedimentary rocks which, though widespread at the surface, form only a comparatively small part of the whole. These are together conveniently referred to as sial. The ocean-beds must, on the other hand, be composed of heavier rocks made up of the silicates of iron, manganese, magnesium, and calcium—the sima of Suess. This conclusion is confirmed by the greater 'magnetic permeability' of the ocean-floor compared with the continents, indicating in the former the presence of ferrous oxide.¹

The distinction between sial and sima appears to be the result of a primæval magmatic differentiation of the outer zones of the Earth into a lighter acid portion consisting mainly of silica with alumina, the alkalies, and much water and other volatile constituents—that is to say, the typical magma of acid rocks such as granites and rhyolites—, and a heavier basic portion corresponding to the magmas of dolerites and basalts, passing doubtless below into that of the still more basic peridotites.

There seems to be no doubt that Suess was right in supposing that the sima extends everywhere below the sial of the continents. There is, however, considerable difference of opinion as to the thickness of the continental sial. Wegener² supposes it to be as much as 63 miles (100 kilometres). This is founded largely on Hayford's level of isostatic equilibrium or uniform density, which he placed at a depth of 71 miles (114 km.). It was afterwards reduced by Bowie to 60 miles (96 km.), which, however, appears to represent the depth of the sial forming the downward extending folds of the Rocky Mountains. Doubtless in the Himalayas it would be still greater, but in plains and plateaux the thickness may perhaps range from 9 to 40 miles (15 to 64 km.).8 It would depend on the elevation of the land and on the density of the sial. Nor is the depth to which the sial extends necessarily the same as that of the depth of uniform density. In the older parts of the continental shields the latter is probably considerably less than the former.

The idea that ocean-depths are the result of foundering is wholly

¹ A. Wegener, 'The Origin of Continents & Oceans' 1924, pp. 32–33.

² Ibid. p. 37.

 $^{^3}$ H. S. Washington's estimate is from 15 to 20 km. (9 to 12½ miles), Journ. Washington Acad. vol. xiv (1924) p. 437.

opposed to the doctrine of isostasy, for it implies that the rocks which form the floor of the oceans are of the same composition as those of the neighbouring continents. This would result in a deficiency in mass of the deep-sea areas compared with the continents, unless indeed there had been a purely local contraction, such as that to which reference has already been made and which has been shown to be in the highest degree improbable.

The only alternative is to conclude that the continental masses of sial can, under the action of continuously applied external forces, slowly drift through the sima, and that they have thus moved apart and left the ocean-deeps between them.

The magma of the granite of the sial must, on account of the large amount of water and other volatile constituents that it contained, have cooled to a comparatively low temperature, say 600° C., before it crystallized. These constituents were, however, eliminated and lost, so that it would thereafter require a much higher temperature to melt or even soften the rock, and the sedimentary constituents of the sial would (as a rule) prove equally refractory.

The basic rocks that constitute the sima, especially if they are rich in iron, are on the other hand less affected by the loss of volatile constituents. We may therefore expect that, at a temperature corresponding to comparatively moderate depths, they would become to some extent plastic.

The principle of isostasy appears in fact to depend on the circumstance that, given sufficient time, by no means very long from the geological standpoint, the sima acts as a whole as a fluid in which the sial floats, to use Airy's simile, like a log in water, or in Wegener's words, like ice-floes in the sea, although, it need scarcely be said, the viscosity of the sima (even at a fairly high temperature) is many thousands of times that of water. There is, therefore, nothing surprising in the blocks of sial making their way through the sima, accompanied, it may be, by crystallized sima adhering to their lower surfaces.

It is to the major fissures of the Earth's crust which are represented by the ocean-deeps that we must look for the fundamental cause of igneous activity in regions of tension. As the fissure opens the underlying sima magma will rise, in order to re-establish a condition of isostasy. This will be facilitated by the fact that the accompanying release of pressure will render the magma fluid, and at the same time cause it to expand. This expansion will be all the greater, on account of the volatile constituents in the

magma. Its density will of course diminish correspondingly, and it will rise higher in the fissure than it would otherwise have done.

In the course of time, however, a large proportion of the volatile constituents will escape, crystallization commence, and the density increase, so that the column will sink to a certain extent.¹

Some idea of the depth from which the sima of ocean-deeps rises can be gathered from the temperature of igneous magmas. Dr. H. H. Thomas, from an examination of the metamorphism of the xenoliths in the Loch Scridain magma-reservoir, arrived at the conclusion that it was initiated at a temperature of nearly 1400° C.² This figure rests on experiments with dry melts, and must, he thinks, be reduced, if the presence of water under pressure be taken into account. Some heat may have been lost while the magma was rising, and during the course of its intrusion; but there may have been a slight accession of temperature from oxidation or radio-activity. We may, however, assume for purposes of illustration that the temperature in the original position of the magma was in the neighbourhood of 1400° C.

According to the calculations of Prof. L. H. Adams, which appear to rest on a sound basis,³ this temperature would be ordinarily found at a depth of about 72 miles (115 km.). This actual figure is, at best, a conjectural estimate; but it would seem probable that some parts at least of the magma of igneous intrusions must come from a depth that cannot have been very much less. It would therefore seem that the formation of these major fissures presents the most probable means by which material from great depths has reached the neighbourhood of the surface, a conclusion which is of some importance in considering the source of the metalliferous ores.

Before the opening of a fissure differentiation at such depths would be impossible, on account of the extreme viscosity of the magma under heavy pressure, but the release of pressure due to the opening of the fissure would result at once in an increase of

An incidental effect of the formation of rifts would be the lowering of the level of the sea. The area of the deeps lying below 15,000 feet (4573 metres) is about a third of that of the whole ocean. If, then, a tenth of these came into existence as rifts about the same time, in consequence of an average sinking of 7500 feet (2287 metres), the surface of the sea would be lowered by about 250 feet (76 metres). These figures are, of course, only intended to show that the effect would not be negligible.

² Q. J. G. S. vol. lxxviii (1922) pp. 250-54, & 'Island of Mull' Mem. Geol Surv. 1924, p. 278.

³ Journ. Washington Acad. vol. xiv (1924) p. 468.

fluidity. The first differentiation would be, in all probability, a repetition of the primordial process of differentiation into basic and acid magmas already mentioned, for the sima would appear to be capable of yielding another but smaller crop of an aqueous acid magma. This would be followed by further differentiation by crystallization due to cooling as well as to loss of volatile constituents, with the result that ultimately a wide range of igneous rocks would be evolved.\(^1\) Before, however, differentiation had advanced very far, a series of lateral intrusions from the major fissures would have commenced. The flow of the deep sub-crustal sima towards the fissure would cause a temporary sinking of the adjoining crust, simultaneous with the rise of the magma in the fissure, with the result that, for a portion at least of the length of the column filling the fissure, the pressure of the magma would exceed that of the surrounding rock, so that intrusion would take place. As differentiation proceeded in the intruded magma, the progress of the segregated acid magma would be retarded by local viscidity, caused by the loss of a portion of the volatile constituents and by cooling at the surface of contact with the adjoining rock. This would not be the case with the ultrabasic and basic magmas below it (which would form by far the greater portion of the whole), as they contain less volatile constituents, and are less dependent on them for its fluidity. The ultrabasic and basic magmas would, therefore, progress more rapidly than the acid magma. In so doing they would let down the still fluid portion of the acid magma above them until the latter reached the level of their flow. Here it would be protected from loss of volatile constituents, and the temperature of the surrounding rock would, by this time, have become little less than that of the magma itself. The acid would, therefore, follow the basic magma in the channel of intrusion, a succession which corresponds very closely to the order of intrusion of plutonic magmas in the West of Scotland and at the Lizard.2

¹ That the first stage of the differentiation of igneous rock is into an acid and basic magma is, to my mind, abundantly proved by W. A. Richardson's & G. Sneesby's analysis of the frequency of igneous magmas of different silica percentages. This clearly shows two distinct peaks, one acid and the other basic; see Min. Mag. vol. xix (1922) pp. 303-13.

² I have long advocated such an explanation of the order of intrusion of plutonic rocks in my lectures at the Imperial College of Science & Technology. I may add that the ultrabasic magma would move more rapidly than the basic: for, on account of the excess of the density of the basic magma over that of the adjoining rock, the maximum difference of pressure will occur below it.

How far this lateral penetration will extend, and what form it will take, depend on the nature and structures of the rocks, and the earth-movements that may supervene. A magma may travel a considerable distance horizontally, or with a gentle inclination upwards-without any manifestation, other than the filling of fissures at right angles to the prevailing tension—until it meets with an obstacle, such as deeply-rooted mountain-folding, when it may form a tumefaction in the nature of a laccolith which will become a centre of igneous activity, and give rise to radiating and concentric structures as well as plutonic rock-masses, or it may well out in fissure-eruptions. Its progress and manifestations will be due partly to the hydraulic pressure to which it is subjected, and partly to the expansive force of its volatile constituents, and these will be assisted in some cases by faulting, bringing the magma into contact with rocks under less pressure, into which it will penetrate along joint- or fault-planes.

Of all these manifestations of igneous activity it is the occurrence of parallel dykes that is usually the most widely extended both in space and in time, and affords the most satisfactory evidence of the area throughout which a subterranean magma has spread—so far at least as it is accompanied by a prevalence of tensional conditions above it.

If the sima magma, when still in its original position under the heavy pressure of the superincumbent sial, remained at too high a temperature for crystallization to take place, the magma and the rocks differentiated from it would be of the normal types. The temperature-gradient, however, in the great masses of sial (the continental shields of some authors) shows a relatively slow increase in depth: consequently, a comparatively low temperature may be found at their under surface, a temperature sufficiently low for some crystallization to take place.

In these circumstances it may be expected that crystallization will commence with those minerals or groups of minerals that have a small molecular volume, small, that is to say, for the elements which they contain. Corresponding to these there are usually minerals or combinations of minerals having the same chemical composition but greater molecular volumes, which crystallize under low pressures. Among the high-pressure minerals with small molecular volumes are garnet, zoisite, epidote, kyanite, muscovite, biotite, and diamond. The low-pressure minerals with large volumes include anorthite, orthoclase, and alusite, and graphite. Albite

and water have relatively large volumes, but have for practical purposes no small-volume representatives.

Dr. F. Becke has shown 1 that igneous rocks, formed originally at moderate depths, have, when subjected to great pressure, certain minerals changed into others with greater density: for instance, orthoclase into muscovite and quartz, and lime-soda plagioclases into albite and zoisite. He gives the following equation:—

$$\begin{split} x(\text{NaAlSi}_3\text{O}_8) + 4(\text{CaAl}_2\text{Si}_2\text{O}_8) + \text{KAlSi}_3\text{O}_8 + 2\text{H}_2\text{O} \\ \text{albite} & \text{anorthite} & \text{orthoclase} & \text{water} \\ & & & & & & & & & & & & & & & & \\ & & & & & & & & & & & & & & & & \\ & & & & & & & & & & & & & & & & \\ & & & & & & & & & & & & & & & & \\ & & & & & & & & & & & & & & & & \\ & & & & & & & & & & & & & & & \\ & & & & & & & & & & & & & & \\ & & & & & & & & & & & & & & \\ & & & & & & & & & & & & & & \\ & & & & & & & & & & & & & \\ & & & & & & & & & & & & \\ & & & & & & & & & & & & \\ & & & & & & & & & & & \\ & & & & & & & & & & & \\ & & & & & & & & & & & \\ & & & & & & & & & & & \\ & & & & & & & & & & \\ & & & & & & & & & & \\ & & & & & & & & & & \\ & & & & & & & & & & \\ & & & & & & & & & & \\ & & & & & & & & & \\ & & & & & & & & & \\ & & & & & & & & & \\ & & & & & & & & & \\ & & & & & & & & & \\ & & & & & & & & & \\ & & & & & & & & & \\ & & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & & \\ & & & & & & \\ & & & & & & \\ &$$

The figures under the names of the mineral substances other than albite, which is unaltered, express their molecular volumes. It will be found that the total of these volumes under low pressure is 547.1, and under high pressure only 462.5.

When, therefore, plagioclase is subjected to sufficiently high temperature and pressure in the presence of a little water, and is decomposed in the manner described by Becke, the albite portion appears to go into temporary solution, and either recrystallizes as water-clear albite in situ, or is the agent of the albitization of neighbouring rocks, giving rise to the formation of spilites, spilosites, desmoisites, or adinoles. It is reasonable to suppose that the minerals which crystallize out from amorphous magmas under heavy pressure will be similar to those into which other minerals already crystallized are transformed under similar conditions of pressure and temperature.

It is, however, the garnets which are chiefly characteristic of rocks that crystallize under especially heavy pressure. Dr. L. L. Fermor ² has described the occurrences of rocks in the Province of Vizagapatam (India), which appear to have been crystallized under such conditions.

¹ 'Ueber Beziehungen zwischen Dynamometamorphose & Molekularvolumen' Neues Jahrb. vol. ii (1896) pp. 182–83.

² 'Garnet as a Geological Barometer & an Infra-Plutonic Zone of the Earth's Crust' Rec. Geol. Surv. India, vol. xlii (1913) pp. 41–47.

These rocks are characterized by the presence of garnets which, under normal conditions of crystallization, would have been replaced by anorthite, augite, diopside, hedenbergite (iron-diopside), wollastonite, olivine, tephrite (manganese-olivine), and magnetite. The garnetiferous rocks are calculated by Dr. Fermor to occupy 20 per cent. less space than their low-pressure equivalents. They contain orthoclase, although this, as we have seen, may be transformed under special conditions of pressure into muscovite and quartz, but they contain no soda-minerals. Presumably, under the conditions that prevailed, these would remain in the fluid state the longest, and only crystallize when the temperature had been lowered still more. Apparently, they were pressed out in the fluid state from the Vizagapatam rocks, on a release of pressure, before this happened. These rocks appear to be made up of minerals which have crystallized out at great pressure below the under surface of the sial crust. Their crystallization must have left a magma rich in soda and comparatively poor in the oxides of divalent minerals, such as lime, magnesia, and ferrous and manganous oxides. We may expect a magma of this character to occur, either alone or in association with typical sima magma, in the molten magma arising from great depths in fissures formed in regions of tension. Such a magma is one that would give rise by differentiation to the series of alkali-rocks. These are characterized by low proportions of iron, lime, and magnesia, and an excess of potash, soda, and frequently alumina. In normal rocks the alkalies and lime of the felspars are accompanied by an equal molecular amount of alumina. The magnesia, the iron-oxides, and the remainder of the lime are also usually associated in many monoclinic pyroxenes and amphiboles with alumina. If a considerable proportion of the magnesia, iron-oxides, and lime be removed in the form of garnets, less than one-third of the equivalent proportion of alumina will go with them, so that it is not surprising that the percentage of alumina in the residue should be high, especially if, as appears frequently to happen, little or no zoisite or epidote is formed. In some instances, however, a certain number of the garnets formed at great depths are carried up with the alkaline magma.

The alkali-rocks are sometimes found alone, as in the neighbourhood of Montreal and many localities on both sides of the Atlantic; but frequently they occur as occasional exceptions in a vast upflow and outpouring of normal rocks, mainly, but not

exclusively, of basic composition. Examples of such modes of occurrence are met with in the Tertiary igneous rocks of the British Isles. Other examples of this association of normal and alkalirocks occur in Scandinavia, India, and Australia.

Beyond the Eastern Atlantic deeps to which reference has been made lies the Central Atlantic bank, rising some 6500 feet (2000 metres) above the ocean-floor on either side of it. It only shows at the surface by virtue of local eruptions of volcanic rocks, mostly basic, but including occasional alkali-rocks, such as those of Rockall, which however is surrounded by a basaltic plateau close below the surface of the sea. The mass of the ridge must, however, consist of acid or sedimentary rocks, such as compose the continental masses. If it were not made up of such lighter rocks, it would not continue to exist. Whenever eruptions or earthmovements may, for the time being, disturb the isostatic equilibrium in any area, the forces of gravity acting on the yielding rocks of the Earth's crust tend to restore it. Whatever may be the inequalities of the depth of the sea, they are compensated by the variation in the density of its bed. The only exceptions are minor irregularities so small that they can be maintained by the strength of the rocks, or so recent that the slow forces of readjustment have not had time to operate.

West of the central ridge is another ocean-deep formed in all probability by the same process of rifting, in the course of which the eastern margin of the North American continent drifted away to the westward. These Atlantic rifts represent far greater relative horizontal movements than those affecting Western Europe, but they seem to be essentially similar in nature. The total displacement, towards the west, of Eastern America relatively to Western Europe would appear to vary from about 3000 miles (5000 km) in the south of the North Atlantic to about 1400 miles (2300 km.) in the north. As Wegener claimed to be the case, the movement seems to have been largely in the nature of a rotation about a point in the far north. He thought, however, that the east of North America and the west of Europe were once actually in contact; whereas, according to my view, they were still separated in later Palæozoic times by an area, much narrower than the present Atlantic, which was sometimes wholly terrestrial and sometimes partly occupied by shallow mediterranean seas with a roughly north-and-south trend, one on the east and one on the west. They seem to have been to a great

extent independent; for the marine faunas preserved in the later Palæozoic rocks of Western Europe are strikingly different from the contemporary marine faunas in Eastern North America, indicating the probable existence of a land-barrier between them. When, on the other hand, marine conditions were replaced by terrestrial, the similarity of the fossils and of the climatic evidences would seem to prove the existence of a continuous landarea.

When the rifting occurred, the rocks of the central land must have been fissured like those of Devon and Cornwall, and slipped away partly on one side and partly on the other, so that they no longer appeared above the sea, nor was the isostatic adjustment sufficient to raise them to the surface. The volcanic accumulations which form islands at various points on the central bank show a local excess of gravity. This indicates that their elevation is comparatively recent, so that isostatic adjustment is not yet complete. When it is, they may be wholly submerged, an event which would be hastened by subaërial and marine erosion.

On the continent of North America there is evidence of faulting near the coast, with a downthrow towards the Atlantic, in post-Triassic times. Though parallel with the Alleghany folds, it is so much later that it must owe its existence to independent causes It is believed to be of Jurassic age, and associated with the 'foundering of the Appalachian continent to the east and southwest' of Connecticut, leaving 'the Eastern Highland' of that State as a horst.¹ It is possible too that, on the North American continent east of the Cordilleras, a region of tension existed in Mesozoic and later times, and that we owe to it numerous well-known occurrences of alkali-rocks.

A similar succession of events appears to have taken place in the South Atlantic. There the remarkable resemblance between the rocks on the opposite shores—ranging from the Devonian to the Jurassic—, both in lithological characters and in fossil contents, seems to lead almost inevitably to the conclusion that they were once in much closer proximity, though probably not in actual contact, as supposed by Wegener, for there too is an important mid-oceanic ridge, from which volcanic islands rise to the surface. I am not aware of any evidence of tension on the east coast of America, but the occurrence of alkali-rocks points to its existence.

¹ Wilbur G. Foye, Geol. Soc. America, Preliminary List. Monday-Wednesday, Dec. 29-31, 1924.

On the west of South Africa slip-faults of post-Dwyka or even post-Beaufort age, and therefore Mesozoic or post-Mesozoic, occur more or less parallel to the coast; but some at least have a hade and downthrow to the east, and, though there are others which are believed to throw down to the west, there is no definite evidence of a general subsidence towards the Atlantic. Here also alkalirocks occur.¹

In the south the great Worcester Fault or group of faults with a downthrow to the south extends east and west at least 70 miles. It is parallel to, but later than, the early Mesozoic folding of the Cape ranges, and is, as claimed by Dr. R. H. Rastall, of post-Uitenhage, and therefore post-Neocomian age.²

Parallel to this, and of about the same date, is the Zuurberg fault-system, extending east and west for 100 miles, and constituting a trough-fault. There are also other east-and-west faults of post-Neocomian age with the same strike. These east-and-west faults are not parallel to the coast east of Algoa Bay, which trends roughly west-south-west and east-north-east, and for some unknown reason traverses the strike of folds and faults alike.

On the east coast, near Port St. John, there are faults with the same strike and of similar age, while inland there are numerous basic dykes of late Triassic or Jurassic age. These vary considerably in direction, but those with a west-north-west and east-southeast strike seem to be the commonest. Near Port Shepstone there is faulting with an east-north-east and west-south-west strike and a downthrow to the south-south-east.

In Natal east-and-west faulting again occurs near Colenso. Elsewhere there are many post-Karroo faults, varying in strike from north and south to east-north-east and west-south-west, between the Drakensbergen and the coast, to which some of them are nearly parallel.

Farther north in East Africa, as is shown by Dr. E. O. Teale and Mr. R. C. Wilson in an interesting paper on Portuguese East Africa,³ there are two main directions of faulting, of late Mesozoic or Tertiary age. One is south-west and north-east, or south-

¹ I am indebted to Dr. A. W. Rogers, Director of the Geological Survey of South Africa, for much valuable information on the faulting of South Africa. Prof. E. H. L. Schwartz has also written on the subject: see S. A. Journ. Sci. 1916, pp. 367–82.

² Q. J. G. S. vol. lxvii (1911) pp. 705, 721-22, 726-31.

³ Geogr. Journ. vol. xlv (1915) pp. 15-45.

south-west and north-north-east, and the other north and south the strike of the great rift-zone of East Africa. These authors point out that the effect of these two directions of fracture is seen in the repeated alternation of northerly and north-easterly trends in the coast of East Africa and Madagascar. Dr. Teale informs me that there are numerous dolerite-dykes in the frontier-zone of Portuguese East Africa with a dominant northerly strike. Such dykes are also numerous near the eastern edge of the crystal-line rocks bordering the low country and the younger rocks, but there the prevailing strike of the dykes is about north-north-east.

It is in the extended tract, characterized by 'Graben' or riftvalleys, that stretches from the east-and-west Tertiary folding of the Taurus Mountains of Asia Minor to the similar folding of early Mesozoic age in South Africa that the most striking evidence of tension is to be found. 1 E. J. Wayland 2 and V. Uhlig 3 have, it is true, contended that the rifts are the result of east-and-west compression and parallel overthrust faults oppositely directed; but, in all the regions of compression in different parts of the world that have been examined, there is nothing comparable to this great succession of rift-valleys.4 They include the central valley of Syria, the Gulfs of Suez and Akaba, the Red Sea and the Gulf of Aden, and at least three more or less parallel zones in Eastern tropical Africa. The eastern zone, which coincides in part with the east coast of Africa, dates from the Miocene Period, while the central and western zones are successively later, but in all of them movements continue to the present day.

The typical structure consists of a series of slip-faults with their hades and downthrows directed towards the axis of each rift, which is frequently occupied by an elongated lake, of which Tanganyika and Nyasa are examples. The crustal activity is expressed in earthquakes and volcanic eruptions, the latter largely of alkaline types.

An interesting feature is the low value of the force of gravity

¹ See J. W. Gregory, 'Rift-Valleys & Geology of East Africa' London, 1921; also E. Krenkel, 'Die Bruchzonen Ost-Afrikas' Berlin, 1922, and Geol. Rundsch. vol. xiv (1924) pp. 209–32.

 $^{^{2}\,}$ Geogr. Journ. vol. lvii (1921) pp. 239–40 ; ibid. vol. lviii (1921) pp. 344–59.

³ Geogr. Zeitschr. 1907, p. 478; 'Beitrage zur Kenntnis der Geologie & Petrologie Ost-Afrikas' Centralbl. f. Min. 1912, p. 559.

⁴ It must be remembered, however, that W. Salomon has expressed similar views with reference to the rift-valley of the Rhine. See *ante*, p, c.

in the rifts. This is presumably due to the stretching of the sima below, the fissuring of the sial, and the infilling of such fissures by material from the surface more or less broken up, brecciated, and uncompacted. Sooner or later, isostatic adjustment will be obtained by the inward and upward flow of the sima, the consolidation of the infillings, and the deposition of new sediments. In the Red Sea and in the Gulf of Aden, on the other hand, there is an excess of gravitation due in all probability to a lava-flow occupying their floors.

The tension that has given rise to the rift-valleys has been attributed to various causes. Some authors have considered it to be due to an anticlinal curvature with its axis parallel to the rifts. I have already given reasons for my belief that such a structure cannot give rise to important faulting, and, as a matter of fact, no such anticline is visible. In some places, there is, it is true, a local dip away from the rift in its immediate neighbourhood; but this is due to a tilting-back of the faulted blocks, similar to that seen in the basalt-flows of Skye and on the margins of the Rhine Valley.

Others have attributed the rifting to the pressure accompanying the east-and-west folding in the extreme north and that in the extreme south of the rift-zone. Such a pressure might produce overthrusts with a strike parallel to that of the folds, or, according to Daubrée's experiments, two lines of fracture making equal angles with the direction of pressure and roughly at right angles one to the other, but not tensional fractures parallel to the direction of pressure. It must also be remembered that the folding on the north was not contemporaneous with that on the south.

Everything points to a long stretch of country subjected to tension due to external forces, as the result of which the areas on the east and west of the rift-zone have receded one from the other.

The whole rift-zone persists in a remarkable manner for nearly 2000 miles (say 3000 kilometres) almost undisturbed by variations in the nature and structure of the rocks through which it passes.

In Southern Rhodesia an older region of tension, with approximately the same direction, is indicated by a broad norite-dyke 3 to 4 miles (5 to 7 kilometres) wide extending for 300 miles (500 kilometres) from north to south. There is no actual proof that it is older than the Karroo Beds; but it has evidently suffered considerable erosion, and is usually believed to be of pre-Cambrian

age, on account of the similarity of its petrology to that of the Boschveldt laccolith.

Much of the structure of the African continent has yet to be determined; but, so far as it is known, it appears everywhere to support the view that there is evidence of the prevalence of tension directed outwards from the centre. This is in accordance with Wegener's contention that at the beginning of Mesozoic times there was a great 'Ur-Kontinent', of which Africa was the centre, and that it has since been broken up by a relative movement of South America to the west, of West Antarctica to the south-west, of India to the north-east, of Australia to the east, and East Antarctica to the south-east.

Dr. R. Staub ¹, however, contends that, like India, Africa itself has moved northwards, and has given rise to the Eocene (Alpine) folding of Europe.

There is reason to believe that regional tension has also existed in Madagascar and India: this is confirmed by the presence of alkali-rocks and basaltic flows, and Prof. J. W. Gregory has recently described a number of rift-valleys striking north and south, or north-west and south-east, in Northern Yunnan.²

Recently Prof. W. Howchin has shown, too, the existence in the St. Vincent and Spencer Gulfs of rift-valleys of post-Eocene age with a nearly north-and-south direction. On the east, in the State of Victoria, there is a series of apparently related slip-faults the strike of which varies from north-north-east in the west to east-north-east in the east.³

Regional tension of Mesozoic and Tertiary age is thus very widespread; but it is naturally missing as a rule in regions where compression then prevailed, resulting in folding and thrusting, especially the Pyrenees, the Alps, and the Himalayas.

The question of the origin of regions of tension must now be considered. Why should they exist, or, to go one step farther

^{1 &#}x27;Der Bau der Alpen' Berne, 1924, pp. 7-8.

² J. W. Gregory & C. J. Gregory, Phil. Trans. Royal Soc. ser. B, vol. cexiii (1925) pp. 242-47.

³ W. Howchin, Trans. Roy. Soc. S. Austral. vol. xxxy (1911) pp. 47–59, and Proc. Austral. Assoc. Adv. Sci., Melbourne Meeting, 1913, pp. 148–78, 1914; E. O. Teale, Trans. Roy. Soc. S. Austral. vol. xlvi (1922) pp. 160–65; and information received from Prof. E. W. Skeats and Mr. Baragwanath, Director of the Geological Survey of Victoria.

back, why should different portions of the continental masses tend to move apart from each other?

On the whole, the movement and the corresponding tension are roughly east and west, though frequently more or less diverted by local circumstances.

This prevalent direction naturally suggests that it is in some way determined by the rotation of the Earth, and is a result of tidal retarding action. Now, the rate of the retardation of the Earth's rotation is known from astronomical evidence to be approximately an increase of 9 seconds in a century, per century, 1 and there seems reason to believe that this may all be accounted for by the friction of tidal currents in shallow seas (that in the oceans being negligible), so that it is apparently unnecessary to call in friction produced by the tides in the solid substance of the Earth. It is claimed too that these tidal movements are so small—of the order of 1 metre, or 10^{-7} of the Earth's linear dimensions—that the Earth must be considered for this purpose as perfectly elastic, and that any purely elastic distortion of the Earth can have no retarding effect.²

The first objection ignores the fact that, if there is a tidal deceleration, there is also an acceleration due to the secular contraction of the Earth, which must, as I hope to show on another occasion, be considerable. Even the decrease in the ellipticity of the Earth, itself due to a decrease in the velocity of its rotation, involves an acceleration which prevents that decrease from being so great as it otherwise would be. The retardation of the Earth's rotation is, therefore, the difference between a decelerating and an accelerating effect, and these may be and probably are much greater than the difference between them. In other words, the deceleration, which is the measure of the effect of tidal friction on the Earth, is equal to the retardation deduced from

¹ That is to say: the length of a day now is $9/100 \times 365\frac{1}{4}$ of a second more than it was a century ago. It is usually assumed that this retardation affects the entire mass of the Earth, whereas it is probable that the retardation of the Earth's upper zones is slightly greater than that of the interior. If this be so, a correspondingly less amount of friction will be required to produce the observed result.

² H. Jeffreys, 'The Earth' 1924, chap. iv. The effect of 'elastic viscosity' (which involves permanent set or flow) is excluded where the periods of distortions are as short as those of the tides: for it is known to be inoperative with the Euler nutation, the period of which is considerably longer—fourteen months.

astronomical observations plus the acceleration due to the Earth's contraction and change of form. Indeed, it is possible that, at an earlier period, the acceleration may have been greater than the deceleration.

With regard to the second objection, I have recently shown 1 that the tidal distortion in the more superficial zones of the Earth is much greater than in those at greater depths; and it would appear that in the former the ratio of the distortion to the total thickness of the zones would be of the order of 5×10^{-6} , fifty times as much as for the whole Earth. Therefore the internal friction (the hysteresis, so to speak) in elastic distortion may not be negligible—especially as the outer crust is far from homogeneous, being subject to numerous forms of discontinuity, such as, on a small scale, the boundaries of crystals, sand-grains, pebbles, and fragments, besides planes of weakness in the crystals themselves, and, on a large scale, stratification, lamellation, foliation, cleavage, joints, faults, unconformities, and intrusions. Everywhere there are occasions of imperfection and inequality in mutual mechanical reactions, so that elastic distortion must frequently give rise to movements between surfaces in contact, with resulting friction and absorption of energy. In many cases forces tending to produce such a result are already acting, and only require a slight addition in order to overcome the resistance opposed to them.

There seems, therefore, every reason to suppose that there are, even apart from the friction in shallow seas, forces tending to retard the rotation of the Earth and especially of the outer zones, consisting mainly of crystallized igneous rocks and sediments, and thus to produce a movement of the exterior relatively to the interior from east to west.

There is another possible source of surface-retardation of which I would speak with less confidence. The records of horizontal pendulums at Potsdam show that even at a depth of 80 feet (25 metres) there are, besides the movements due to the joint effect of the attraction of the sun and moon on the pendulums and of the tidal waves in the crust, diurnal and seasonal movements of still greater amount, which appear to be caused by tilting due to the heating effect of the sun on the Earth's surface. It has been shown that these are not dependent on purely local conditions;

¹ 'Nature' vol. cxiv (1924) p. 749.

but the extent of the area in which the interchange of day and night and of summer and winter affects the instruments is not known. It is, however, obvious that the distortions caused by heat must travel across the continents from east to west. As they cannot be true elastic movements, but involve friction and other mechanical effects, it seems reasonable to suppose that they will (in the course of time) cause a relative movement between the crust and the interior of the Earth, even though they may leave the total momentum of rotation practically unaffected.

These considerations unfortunately leave unexplained the divergent relative movement from Africa of the other constituent parts of the 'Ur-Kontinent'—why the Antarctic continent should have drifted to the south or (alternatively) Africa to the north, or why America should have been retarded by tidal friction more than Europe-Africa, and Africa more than India and Australia.

There are, however, other possibilities that may explain the relative movement of portions of the Earth's crust. According to Wegener, the sial, which in primæval times had covered the sima over the whole Earth, had in the late Palæozoic Era been restricted, so as to extend over little more than the fourth part; but it had become at the same time correspondingly thicker, as a result of the extensive folding that it had suffered. It then (as already stated) occupied a single area, of which what we now know as Africa was the centre, although there is evidence that some portions were covered by shallow seas, just as the present Mediterranean Sea now covers a part of the Old World continental area.

We have seen that since Hercynian times it has split up, different portions moving away in different directions. The evidence adduced by Wegener renders this at least a plausible hypothesis. He ascribes these changes to different rates of westward movement, and a drift away from the Poles; but a general drift from the centre of Africa to the centre of the Pacific seems to represent the real character of the movement more happily. Prof. H. Darwin explained such a movement by the hypothesis that the moon was, some 500,000,000 years ago, thrown off from what is now the Pacific, and took with it much of the lighter surface-rocks, the sial in fact, which then occupied that part of the Earth, and that the remainder has since been drifting towards the region of high density thus caused; although it would seem to have been held back by the resistance of the floor of the Pacific and this has given rise to the circle of folded mountains which

surrounds that ocean. Dr. H. Jeffreys, however, believes that the Earth gave birth to the moon when the young mother had herself only existed some 10,000 years, and that this must have occurred more than 1000,000,000 years ago. He gives reasons for believing that the Earth was then almost fluid, with at most a thin solid crust on the outside, which, in the violent agitation that took place during the process, must have been broken into fragments which would have forthwith spread themselves out in such a way as to become roughly distributed over the Earth.2 In any case, it would be inconceivable that the drifting towards the centre of the Pacific should have been delayed until nearly the end of the Palæozoic Era. Of course, if the birth of the moon could have taken place in late Palæozoic times, when the Earth's crust was already consolidated, and if it could have occurred, while allowing life to go on much as usual in other parts of the globe, there is no reason why the drift should not have taken place in Mesozoic and Kainozoic times: but, according to Jeffreys, the want of fluidity in the upper zones of the Earth would then have rendered the separation impossible. Another objection to such an hypothesis is that there have been, during Palæozoic times and the long ages of the pre-Cambrian Era, repeated occurrences on a large scale of mountain-building, folding, thrust- and slip-faults, and igneous intrusions and extrusions, so that there must have been repeated previous transformations similar to those that we can trace with greater distinctness in the immediate past. We cannot explain each of these by the birth of a satellite, for there is only one now existing.

There seems, however, to be a simpler hypothesis, which I will briefly indicate. The Earth, as we know, contains a dense core surrounded by lighter material, the upper portion of which constitutes the sima. The sial is, of course, of comparatively insignificant thickness. It has been contended ³ that, in the early history of the Earth, when the resistance to compression and the rigidity were less, the heavy core was, on account of the Earth's rotation, in a state of unstable equilibrium, and that, as a result, its centre

¹ 'The Earth' 1924, Chap. iii, p. 77.

² Ibid. p. 150; J. H. Jeans, Proc. Roy. Soc. vol. xciii A (1917) pp. 413-17.

³ J. H. Jeans, Phil, Trans. Roy. Soc. ser. A, vol. cci (1903) p. 157; W. J. Sollas, Q. J. G. S. vol. lix (1903) p. 180; A. E. H. Love, Phil. Trans. Roy. Soc. ser. A, vol. ccvii (1908) p. 171; and 'Nature', vol. lxxvi (1907) p. 327.

of gravity probably does not now exactly coincide with that of the Earth as a whole. Consequently, at that point on the Equator to which the core is nearest gravitation is at a maximum. As, however, the attraction of the moon and sun results in friction which tends to retard the rotation of the Earth's higher layers more than the interior, the former must have a slow relative movement relatively to the latter. We have seen that there is reason to suppose that, in Palæozoic times, the continental masses of sial were more or less concentrated round what is now Africa, forming the 'Ur-Kontinent' of Wegener. This may well have been due to the fact that the maximum of gravity was then situated in that part of the Earth. If then, during Mesozoic times, the movement of the higher lavers of the Earth had brought the centre of the Pacific into the position of maximum gravitation, the former great Palæozoic continent would tend to break up and drift apart towards the Pacific, and this is what appears to have actually happened. Similar changes may have occurred more than once in the Earth's history since the remote time when the sial was spread over the whole globe.

It has been urged that the forces developed by the tidal action of the sun and moon, although large enough to cause a slow movement of the Earth's crust as a whole, would not suffice to drive masses of sial through the sima, especially in the presence of the much larger compressive forces developed in the crust by the contraction of the Earth's interior; still less to ruck up the Earth's crust to form mountains tens of thousands of feet in height. It seems probable that this objection could also be urged against the adequacy for the same purposes of the forces developed by the variation of gravity from point to point on the globe, or against any combination of these two hypotheses.

To deal fully with this difficulty would involve the consideration of the principles of crustal compression and mountain-building, which I hope to discuss on another occasion. It will, I think, be at present sufficient to remark that, according to my view, it is precisely by the forces of compression that the crust has been folded and overthrust and the great mountain-chains raised up, but that the immediate result is the exhaustion (for the time being) of these forces, and the simultaneous local destruction of the powers of resistance of the Earth's crust, and that it is then, and then only, that the forces tending to cause the drifting of continental masses become free to act.

There the matter must be left for the time being.

I have dealt but incompletely with a subject of great importance which has not hitherto received the attention that it deserves. I have, I must admit, not had time to examine fully all the data available, especially those of Central and Eastern Europe and North America, while over the greater part of the Earth's surface such data hardly exist. If I have shown you something of the interest and significance of regions of tension, and afforded some inducement for others to investigate the problems which they present, I am more than satisfied.

I wish here to express my thanks for the great assistance that I have received from many quarters in accumulating the data set forth in the preceding address. I have endeavoured, wherever possible, to acknowledge this assistance in the text or in the notes.

[I have now learnt that Mr. W. B. Wright has independently arrived at conclusions very similar to my own on the relation between the great ocean-deep, south-west of the British Isles, and the tension to which the widespread north-west-and-south-west dykes bear such striking witness. I may add that F. von Richthofen connected the great block-faulting which he believed to exist in Eastern Asia with the Tuscarora Deep.²]

¹ I may quote the words of E. Krenkel, Geol. Rundschau, 1924, p. 232, when speaking of the rift-zone of East Africa: 'The comparison with other terrestrial regions of tension, which is now in progress, will certainly throw much new illumination on its development and on the important, hitherto too little regarded, tension-phenomena in the Earth's crust'.

² 'Geomorphologische Studien aus Ostasien: iv.' Sitzungber. K. Preuss. Akad. Wissensch. 1903, pp. 886-87.

February 25th, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Cecil Edward Redmill, B.Sc., 3 Manby Grove, Stratford, E. 15, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

- 1. 'The Geology of Cader Idris (Merionethshire).' By Prof. Arthur Hubert Cox, D.Sc., Ph.D., F.G.S.
- 2. 'The Dissection of Pitching Folds.' By Prof. Arthur Hubert Cox, D.Sc., Ph.D., F.G.S.¹

Prof. Cox exhibited rock-specimens, microscope-sections, and lantern-slides in illustration of his paper on Cader Idris, and a model in illustration of his paper on pitching folds.

March 11th, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Charles Weatheritt Scott, B.Sc., M.I.M.E., H.M. Junior Inspector of Mines, Leybourne House, Regent Street, Stoke-on-Trent, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:-

- 1. 'The Geology of the Llandovery District (Carmarthenshire).' By Owen Thomas Jones, M.A., D.Sc., F.G.S., Professor of Geology in the Victoria University of Manchester.
- 2. 'The Llandovery and Associated Rocks of Garth (Breconshire).' By Gerald Andrew, M.Sc., F.G.S.
- 3. 'The Relations between the Llandovery Rocks of Llandovery and those of Garth.' By Gerald Andrew, M.Sc., F.G.S., and Prof. Owen Thomas Jones, M.A., D.Sc., F.G.S.

¹ Withdrawn by permission of the Council.

March 25th, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Birbal Sahni, M.A., D.Sc., Professor of Botany in the University of Lucknow (India), was elected a Fellow of the Society.

The List of Donations to the Library was read.

The following communications were read:—

- 1. 'On the Clay Pebble-Bed of Ancon (Ecuador).' By Charles Barrington Brown, M.C., M.A., F.G.S., and Robert Ashley Baldry, B.A., F.G.S. (Read by Dr. J. A. Douglas, M.A., Sec.G.S.)
- 2. 'The Pre-Cambrian Volcanic Rocks of the Malvern Inlier.' By John Isaac Platt, M.Sc., F.G.S.

Diagrams were exhibited in illustration of the paper by Mr. C. Barrington Brown & Mr. R. A. Baldry, and rock-specimens and lantern-slides were exhibited in illustration of Mr. Platt's paper.

April 22nd, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communication was read:—

'The Stratigraphy and Palæontology of the Laki Series (Lower Eocene) of Parts of Sind and Baluchistan (India).' By Winfred Laurence Falkiner Nuttall, D.F.C., M.A., F.G.S.

Lantern-slides were exhibited in illustration of Mr. W. L. F. Nuttall's paper.

A quartzite-pebble (supposed to be a dreikanter), from a coalseam at Ashby-de-la-Zouch, was exhibited by Mr. H. G. Mantle, F.G.S.

May 6th, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Geoffrey Chambers Flower, 42 Nevern Square, S.W. 5, and Noel Ewart Odell, A.R.S.M., 44 Compayne Gardens, South Hampstead, N.W. 6, were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. EDWARD BATTERSBY BAILEY, M.C., B.A., F.R.S.E., F.G.S., then proceeded to deliver a lecture on the Tertiary Igneous Geology of the Island of Mull, illustrated by lantern-slides.

He asked his hearers to remember that he was only one of a small group of workers who had recently been employed in adding to our knowledge of the geology of Mull. In the Geological Survey Memoir (1924), the share of each participant is indicated by initials.

The columnar lavas of Staffa and South-Western Mull were described, with especial reference to Scrope's double-tier jointing, Iddings's explanation of the apparent repugnance of approaching columns, and Macculloch's tree that stands upright although submerged in lava.

Attention was then focussed upon Judd's region of central pneumatolysis (propylitization), where, within an area measuring 15 miles in diameter, it is impossible to find a lava that has

retained its olivine undecomposed.

Judd's conception of central subsidence was next discussed. It now appears, from the disposition of lava-types and other considerations, that central subsidence culminates in two adjacent calderas. The occurrence of many pillow-lavas within one of these calderas—at the centre of a manifestly terrestrial volcano—points to the frequent presence of a crater-lake. The crater-hollow must have been renewed by intermittent subsidence—for instance, Kilauea and Askja. The rim-craters of Askja may be taken as a surface-manifestation of a ring-dyke. Ring-dykes are numerous in Mull, where their most perfect example is the Loch Ba felsite, traced by Mr. W. B. Wright and Mr. J. E. Richey. Ring-dykes are known at other British Tertiary centres, and also at Glen Coe and Ben Nevis. Many ring-structures occur in Iceland, in addition to the Askja caldera, and have been described by Thoroddsen. At Oslo they appear in Brögger & Schetelig's map (1923).

There is conspicuous folding in Mull attributable to the lateral expansion of an early ring-dyke. Similar folding does not recur in connexion with later ring-dykes. These may, in some cases, have made room for themselves by stoping en masse, and in others by pushing country-rock inwards towards a central orifice.

Several ring-dykes in Mull show gravitational differentiation,

and the lecturer explained that he had been convinced by Dr. H. H. Thomas and Mr. A. F. Hallimond that this had taken place during crystallization.

Cone-sheets were passed in review, and emphasis laid on their

great aggregate bulk.

Finally, the Mull swarm of north-westerly dykes was considered. The dyke-swarm owes its location to the previous development of the central conduit. One of its members, with ash-vents distributed along its course, has furnished Dr. B. N. Peach and others with a convincing analogue of the Laki fissure in Iceland. Probably, many of the Mull dykes fed fissure-eruptions, as Sir Archibald Geikie long ago maintained; but the products of most, if not all, of these eruptions have been eroded away.

May 20th, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

John John Thomas, Hawthorn Villa, Kendal (Westmorland), was elected a Fellow of the Society.

The List of Donations to the Library was read.

On behalf of Mr. Henry Dewey, F.G.S., Palæolithic implements of Chellean type found in the gravel of Hyde Park, London, were exhibited, and the following observations sent by him were read by the President:—

'The implements on the table were all collected by me from gravel thrown out of a deep trench in Hyde Park. The trench has been dug in order to repair an old disused sewer, and has proved a thickness of upwards of 26 feet of gravel and sand. The dimensions of the pit are: length = 44 feet; breadth = 14 feet; depth = 40 feet. The London Clay has been exposed at the northern end of the excavation, but falls suddenly at the southern end to an unknown depth. The gravel, therefore, covers a step-like feature, which curves round from west-and-east to north-east. The stones are principally Chalk-flints; but perhaps 2 per cent. are quartzite-pebbles from the Bunter pebble-beds and white vein-quartz. One of the quartzite-pebbles measured 10 inches in length; on a smooth side deep striæ scored the stone. They resembled true glacial striæ.

The implements were all taken from material that had been removed from a depth of 26 feet. They include one hand-axe of Chellean type; the topmost portion of a second hand-axe; two choppers, worked along the edges, so as to provide a comfortable hold; two long flakes or flake-scrapers; a broad flake or grattoir; and some pieces showing a certain amount of human workmanship. The height of the top of the London Clay at this locality is approximately 63 feet above O.D. The surface of the gravel is at

89 feet.

'The finds may be compared with others in similar spreads of gravel near by. Four implements were discovered in the gravel when the foundations of the Piccadilly Hotel were dug. They are now in the London Museum. All four are very fine examples of Palæolithic flint-work. They are handaxes with sharp straight edges, and no sign of zigzag work is seen on them. They measure about 5 inches in length, and are flaked all over.

'In the gravel underlying the Regent Palace Hotel three similar Palæolithic implements were found. Two are not quite whole: these also are in the London Museum. They are in a condition similar to that of the Piccadilly finds, and are obviously of the same age. The gravel in which they were found lies on the London Clay at an altitude of 56 feet above O.D.

'In Eagle Place, Jermyn-street, and adjacent to the Museum of Practical Geology, two hand-axes were dug out from the gravel in 1910. They are of

much less finished workmanship.

The following communication was read:--

'The Liassic Rocks of the Radstock District (Somerset).' By John William Tutcher and Arthur Elijah Trueman, D.Sc., F.G.S.

June 10th, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

Mr. Leslie Reginald Cox, B.A., F.G.S., exhibited specimens and lantern-slides illustrating the Fauna of the basal Shellbed of the Portland Stone of the Isle of Portland. He stated that the fossils exhibited were collected by Lt.-Colonel R. H. Cunnington, R.E., of Weymouth, during the past year.

On the western coast of the Isle of Portland the basal bed of the Portland Stone is a highly fossiliferous shelly limestone, on the surface of which fossils weather out in an extremely good state of preservation. Owing to the comparative inaccessibility of the exposures, the fauna of this bed has not previously been investigated in detail. The specimens collected by Colonel Cunnington include about 50 species of mollusca, of which 18 lamellibranchs and 9 gastropods are new to science, and several others have not before been recorded from this country. A study of these fossils has, therefore, added considerably to our knowledge of the English Portlandian fauna.

A description by the exhibitor of the mollusca, and by Dr. W. D. Lang of the polyzoa, is now in course of publication in the Proceedings of the Dorset Natural History & Antiquarian Field-Club.

Prof. HERBERT LEADER HAWKINS, D.Sc., F.G.S., exhibited a series of Echinoidea from the Portland Stone and the Purbeck Beds, and explained that the specimens had a peculiar interest by reason of their rarity and good preservation. Before last year only one species ('Echinobrissus' brodiei Wright) was known from the Portland stone, and this form was represented by very few examples, mainly collected in Buckinghamshire. A species of Hemicidaris from the sands was the only other Echinoid recognized in the British Portlandian. The work of Lt.-Colonel Cunnington has revealed three excellent specimens of 'E.' brodiei in the basement-bed of the Portland Stone (and one from the overlying Whit-Bed); and, in addition, adequate material for the study of four other species, with indication of a sixth. collection from the basement-bed comprises 21 specimens, which may be classed provisionally as follows:—

Tetragramma sp nov. A.	2	specimens.
Tetragramma sp. nov. B.	1.0	do.
Trochotiara thirriai (Étallon) var. nov.	3	do.
Trochotiara sp. nov.	1	do.
(?) Trochotiara sp. indet. (radiole).	1	do.
Hemicidaris sp. indet. (radiole).	1	do.
Clitopygus brodiei (Wright).	3	do.

Trochotiara thirriai is a well-known form from the Portlandian of Northern France. The occurrence of two well-marked species of Tetragramma is interesting. This genus is essentially of Cretaceous date, only two species having been recorded from Jurassic strata. Species B shows some resemblance to one of these, the imperfectly known T. rougonense (Cotteau); but species A has an almost Cenomanian aspect. All of the forms will be described and figured at an early date.

At the same time Prof. Hawkins introduced to the Fellows the results of a search made by himself in the Middle Purbeck Series of Durlston Bay, near Swanage, in the summer of 1924. Hemicidaris purbeckensis Forbes (which was collected from that locality about 75 years ago) has not been recorded from England since its first discovery, although it is well known in France. He collected 38 tests (mostly crushed, but otherwise complete) and innumerable detached plates and radioles, in the course of a few days, no fewer than 14 tests being extracted in a single hour. In addition, two specimens of an apparently new form referable to 'Pseudodiadema' sensu latissimo rewarded his efforts. Thus, in the course of a few months, after a delay of three-quarters of a century, the Echinoid fauna of the Portland Stone has been increased sixfold and that of the British Purbeck Series has been doubled; while the number of specimens now known from both horizons has been enormously multiplied.

The speaker commented on the extremely irregular distribution of Echinoids in these and other Jurassic strata—a distribution which leads to such strange anomalies in collecting as those indicated by the exhibit now shown. He suggested that the irregularity might be ascribed to the known tendency of Echinoids to live in restricted clusters (comprising several species of similar ecological quality), which seem to migrate wholesale in successive generations. This explanation seemed more probable than any alternative based on *post-mortem* segregation of empty tests by the action of currents, since in general the specimens were exquisitely preserved, and often retained their radioles and masticatory apparatus.

The following communication was read:-

'On some Occurrences of Spherulitic Siderite and other Carbonates in Sediments'. By Edmondson Spencer, B.Sc., Ph.D., F.G.S.

In addition to the exhibits described on pp. exxvii-xxix, specimens of spherulites from various formations were exhibited in illustration of Dr. Edmondson Spencer's paper.

June 24th, 1925.

Dr. J. W. Evans, C.B.E., F.R.S., President, in the Chair.

Albert George Brighton, B.A., Christ's College, Cambridge; Percy Harrison, F.S.L., Borough Engineer & Surveyor, High Barn, Alkrington, Middleton (Lancashire); and Joseph Slomnicki, A.R.S.M., Geologist, c/o Steaua Romana, Campina (Rumania) were elected Fellows of the Society.

Prof. William Morris Davis, Library Museum, Cambridge (Massachusetts); and Dr. Gerhard Holm, Geological Survey of Sweden, Stockholm, were elected Foreign Members of the Society.

Prof. Paul Lemoine, Paris; Dr. Victor Madsen, Copenhagen; Prof. Paul Niggli, Zürich (Switzerland); Prof. Josef Felix Pompeckj, Berlin; Dr. T. Wayland Vaughan, La Jolla (California), U.S.A.; and Dr. Mikhail Dimitrivich Zalessky, Petrograd, were elected Foreign Correspondents of the Society.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI, Art. 5, in consequence of the non-payment of the arrears of their Annual Contributions.

VOL. LXXXI.

The following communications were read:-

- 1. 'A Sagittal Section of the Skull of Australopithecus africanus.' By Prof. William Johnson Sollas, M.A., Sc.D., F.R.S., F.G.S.
- 2. 'The Faunal Succession in the Carboniferous Limestone and Bowland Shales at Clitheroe and Pendle Hill.' By Donald Parkinson, B.Sc., F.G.S.
- 3. 'On *Cyathoclisia*, a New Genus of Carboniferous Corals.' By Janet Mitchell Marr Dingwall, M.A., B.Sc., F.G.S.

Lantern-slides were exhibited in illustration of the papers by Prof. Sollas and Mr. Parkinson.

Specimens, thin sections, and lantern-slides of *Cyathoclisia*, etc. were exhibited by Miss Dingwall in illustration of her paper.

Specimens from the clay pebble-bed of Ancon (Ecuador) were exhibited by Mr. Charles Barrington Brown, M.C., M.A., F.G.S.

QUARTERLY JOURNAL

OF

THE GEOLOGICAL SOCIETY OF LONDON.

Vol. LXXXI

FOR 1925.

1. On the Skeleton of IGUANODON ATHERFIELDENSIS Sp. nov., from the Wealden Shales of Atherfield (Isle of Wight). By the late Reginald Walter Hooley, F.G.S. (Read by Sir Arthur Smith Woodward, F.R.S., F.L.S., November 7th, 1923.)

[PLATES I & II.]

CONTENTS.

		Page
I.	Introduction	ĭ
TI.	Description of the Skeleton	3
III.	Comparisons with other Species	51
IV.	Conclusions	58

I. INTRODUCTION.

This very fine fossil was obtained from the débris of Wealden Shales, after a fall of the cliff near Atherfield (Isle of Wight). The complete skeleton was probably present when in situ, and the missing portions were carried away by the heavy seas, which scoured the foot of the talus for several days, preventing all search for the bones except at low tide. When its discovery was announced in 1917, the disarticulated bones of the skull were lying scattered among the bones of the body and limbs in many blocks of the matrix. The unfused condition of the elements of the skull proved the skeleton to be that of a young individual, and as, notwithstanding this fact, there were six anchylosed vertebræ in the sacrum,

---SQ Fig.1. -- Skull of Iguanodon atherfieldensis, one-third of the natural size; for explanation, see p. 3. STF SUR ANG 2 So PRF NAR PMX

it was identified as a specimen of *Iguanodon bernissartensis*, and the portion of the integument found was described as belonging to that species. The study of the bones, after they had been cleared of the matrix and restored, has, however, proved the fossil to belong to a new species, and hereafter it will be designated *Iguanodon atherfieldensis*. The estimated length of the skeleton is 6·3 metres (about 21·6 feet).

II. DESCRIPTION OF THE SKELETON.

Skull.

'i The elongation of the facial part of the skull, the transverse expansion of the edentulous portion, the great constriction between that and the frontal area, the broad and square cranial region, and the heavy mandible agree with *I. mantelli* and *I. bernissartensis*. The skull is intermediate in build between the graceful skull of the former and the massive skull of the latter. There is much more curvature of the lower borders of the mandible than in either of those species.

The length of the skull, from the tip of the premaxillæ to the posterior border of the quadrate, is 457 mm. The occipital condyle is missing. If present, it would have added about 43 mm, to the

length. The length of the mandible is 413 mm.

The prefrontals, postfrontals, the bones of the brain-case and palate, with the exception of a portion of the right pterygoid and (?) left palatine, are lost; but, fortunately, all the other elements were found. The predentary, splenials, and prearticulars are missing from the mandible. The extent and relationship of each discovered element can be discerned. Many new facts concerning the skull of Iquanodon have been brought to light. It is proved that some of the bones in the type-skulls of I. mantelli and I. bernissartensis have been wrongly identified, and that their forms and relationships are different from those exhibited in the published figures of them. It is now certain that there is (as one might have expected) an essential similarity in the relationships of the elements of the skull of Iquanodon to those of the American Predentate Dinosaurs, such as Trachodon, Camptosaurus, Claosaurus, Gryposaurus, etc.

Premaxilla.—The premaxillæ (fig. 3, X, p. 10) are edentulous. Their sutural union is clearly displayed. Dorsally, they

EXPLANATION OF Fig. 1, p. 2.

PMX, premaxilla; NA, nasal; PRF, prefrontal; SO, supraorbital; F, frontal; PF, postfrontal; P, parietal; SQ, squamosal; M, maxilla; LA, lachrymal; JU, jugal; QJ, quadratojugal; QU, quadrate; PAR, paroccipital process; OC, occipital condyle; PD, predentary; D, dentary; C, coronoid process; ANG, angular; SUR, surangular; ART, articular; S, splenial; NAR, external narial opening; AF, antorbital fossa; O, orbit; STF, supra-temporal fossa; ITF, infra-temporal fossa; G, groove for the reception of the horny sheath. The broken lines denote the bones and the portions of bones missing.

are produced backwards as a style-like process. Distally, this process becomes flat dorso-ventrally, and overlaps the nasals for a distance of 92 mm. On the anterior dorsal surface in the median line there is a strong, prominent, longitudinal ridge 10 mm. high at its loftiest part, 15 mm. wide, and 55 mm. long. The sides of this ridge are grooved. At 32 mm. from the anterior extremity of the premaxillæ it is divided by a transverse, narrow groove 7 mm. deep. The dorsal lateral borders of the premaxillæ are deeply hollowed by a continuation of this groove. The groove apparently defines the dorsal extent of the horny sheath, and was for its reception. Neither the bony ridge nor the groove appears to be present in I. mantelli or I. bernissartensis. They are not mentioned by Prof. Dollo. Anteriorly and laterally, the premaxille are deeply excavated. They comprise the boundary of the anterior margin of the upper, and the whole of the lower, borders of the external nares. Where the nostrils converge into the nasal passage, the premaxillæ form a very thin septum. Inferiorly they are expanded into a broad, suturally united plate, narrowing posteriorly. At 145 mm. from their anterior extremity they separate into two powerful bars, convex inferiorly and concave superiorly, with their exterior borders much more elevated than the interior. Into the cleft formed by their outward divergence. processes on the anterior dorsal borders of the maxillaries are inserted, and united by suture. Owing to fracture, only 40 mm. of their length remains; but their full extension can be ascertained by articulating the facial bones. They are thus observed to have been produced to a length of 290 mm. from the extreme anterior border of the premaxillæ, and to have been connected with the nasals, prefrontals, and maxillæ, and their posterior ends with the lachrymals, by which they were overlapped. A similar arrangement is seen in Camptosaurus, Claosaurus, Gryposaurus, Trachodon mirabilis Leidy,3 and Telmatosaurus transylvanicus. appendix to his Fourth Note on the Dinosaurs of Bernissart, Dollo 4 refers to the preliminary communication of Cope on Trachodon, and remarks that it does not appear that there was so considerable an extension in *Iguanodon*. It certainly is not apparent from the figures of the skull of *I. bernissartensis*, nor does the plaster cast of that skull in the British Museum (Natural History) exhibit it.

On the palatal surface of the premaxille, near the anterior margin, the surface is extremely rugose. A strong ridge follows the curve of the anterior border, and two protuberances, surrounded by deep pits, are placed on either side of the median suture. Here again we see the means of attachment for the horny sheath.

The palatal plate is 80 mm. wide at the point of greatest

² Id. ibid. vol. ii (1883) pl. ix, fig. 2.

³ E. D. Cope, 'American Naturalist' Sept. 1883, pl. xvi.

¹ L. Dollo, Bull. Mus. Roy. Hist. Nat. Belg. vol. iii (1884) pl. vi, fig. 3.

⁴ L. Dollo, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) p. 247.

expansion, and is pierced by several large foramina for the passage of blood-vessels. The largest is situated in the line of suture. It is elongate in form, and occupies the same position as the foramen in *Crocodilus*, but it has no connexion with the nares. Posterior to the rugose area on the palatal surface, the bone is smooth and transversely coneave, posteriorly becoming much flatter and narrower.

Maxilla.—The maxilla (fig. 2, I & II, p. 6) is a large, triangular bone. Its greatest height = 85 mm., and its greatest length = 270 mm. The inner surface is vertical and flat. Externally, the dorsal half of the bone is much expanded outwards, and overhangs the alveolar border. The anterior third of the outer surface is strongly convex. This convexity lessens posteriorly, but it is continued across the median area to the jugal process. Below this the surface is inclined downwards and inwards to the alveolar groove. On the external surface several neurovascular foramina are to be observed. At 53 mm. from the anterior extremity, the inner half of the broad dorsal border is raised into a strong walllike buttress, 19 mm. high (fig. 2, I, PA, p. 6). Its anterior external surface is deeply concave. This buttress curves outwards posteriorly; between it and the outer edge of the dorsal border, there is a longitudinal groove for the reception of the inferior premaxillary extension. On the anterior dorsal surface of this buttress there is what appears to be a sutural surface, 50 mm. long, for the vomer (fig. 2, I, V). As this buttress fades away, the external edge of the dorsal surface of the maxilla is raised into a thin parapet 32 mm. high. Against the inner face the inferior premaxillary extension articulates, until it is overlapped by the lachrymal, which is intercalated between the hinder end of this parapet and a remarkable, strong, obtuse, rounded process arising from the median dorsal surface of the maxilla (fig. 2, I & III, PA). It forms by its posterior concave border the anterior boundary of the antorbital fossa. Posterior to this process, the dorsal border is excavated, and forms the lower boundary of the antorbital fossa. Contiguous and posterior to this notch, occur two deep oblique grooves which cut through the external dorsal border. grooves are separated by a powerful, outwardly and downwardly directed, sharply ridged process (fig. 2, I, JA) upon which the anterior end of the jugal articulates, almost completely capping it, the outer anterior end of the jugal being intercalated between it and a raised portion of the border of the maxilla, immediately posterior to the antorbital notch. The deep valley posterior to the ridge is 'for the nerves and vessels of the upper jaw'1. The alveolar border is slightly arched. Anteriorly, the alveolar walls for 103 mm. are produced downwards to an equal extent: at this point the exterior wall rapidly recedes, displaying the alveoli, which remain exposed to the posterior extremity.

¹ R. Owen, 'Fossil Reptilia of the Wealden & Purbeck Formations' Monogr. Palæont. Soc. 1854–55, pt. 2, p. 26.

Fig. 2.—One-third of the natural size: for explanation, see p. 7.

Three small, successional teeth in the left maxilla are the only teeth visible. There are 23 alveoli in each border, which is two less than in I. bernissartensis. The alveoli are largest in the median region, and decrease in size towards either extremity. On the internal surface at the level of the roots of the teeth, or where the alveolar parapet joins the substance of the bone, there occurs a series of 23 foramina (fig. 2, II, F) parallel with the alveolar border. They are separated one from the other by small, thin, grooved buttresses of bone. These grooves were doubtless occupied by the dental artery, which gave off branches entering through the foramina.

Interior to the parapet on the external margin of the dorsal border of the maxilla is a flat platform, which forms a portion of the floor of the nasal passage. The posterior border is sharply inclined downwards and backwards, is wedge-shaped, and possesses a sutural surface on its whole extent for the transverse bone (ectopterygoid); see fig. 2, I & II, E.

The anterior extremity of the dorsal border is inclined downwards in such a manner that, when the maxilla is articulated with the premaxilla, a slot is formed which was probably developed for the reception of the horny beak, and marked the limit of its

backward extension.

The maxilla is in connexion with the premaxilla, the lachrymal,

¹ L. Dollo, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) p. 233.

EXPLANATION OF Fig. 2, p. 6.

I. Exterior aspect of the left maxilla. PA, process forming support and articulatory surface for the lower premaxillary extension; PL, process forming support and articulatory surface for the lachrymal; $J\dot{A}$, jugal articulatory process; V, sutural surface for the vomer; E, sutural surface for the ectopterygoid; T, small successional tooth.

II. Interior aspect of the left maxilla. E, sutural surface for the ectopterygoid; G, deep groove for the passage of blood-vessels and nerves to the upper jaw; JA, summit of articulatory surface for the jugal; PL, process forming support and articulatory surface for the lachrymal; M, matrix covering the external wall of the maxilla and the posterior articulatory surface for the lower premaxillary extension; F, series of foramina for the passage of blood-vessels to the teeth; T, small successional tooth.

III. Interior aspect of the left articular and surangular. A, articular displaced from its true position; S, surangular; F, exterior mandibular foramen; PA, ? prearticular facet; AF, articulatory surfaces for the

IV. Exterior aspect of the right nasal. PF, articulatory surface for the upper premaxillary extension; PA, portion of articulatory surface for the lower premaxillary extension; PRF, articulatory facet for the prefrontal; F, foramina.

V. Interior aspect of the right lachrymal. PF, facet for the extremity of the lower premaxillary extension; LD, interior opening of the lachrymal duct; MF, facet for the maxillary process; JP, jugal process.

VI. Orbital border of the right lachrymal. LD, lachrymal duct; S, ledge supporting the prefrontal and supraorbital. Broken lines denote missing portions.

and the jugal externally. The nasals and the prefrontals are not in relation with the maxillæ, which is remarkable, for Prof. Dollo 1 states that they are so in I. bernissartensis. It is impossible, from the figure of the skull of I. mantelli, to discover their connexions 2

Nasal.—Only the right nasal (fig. 2, IV, p. 6) has been discovered. It has lost by recent fracture portions of its dorsal anterior and posterior extremities. It is, in any case, a comparatively small bone, the outer surface of which is pierced by two foramina. The anterior dorsal surface is slightly excavated for the reception of the dorsal process of the premaxillæ (fig. 2, IV, PF). The anterior lower border is gently curved, and forms the upper posterior boundary of the narial opening. The dorsal border of the inferior premaxillary extension is intercalated between the ventral border of the nasal and a thin plate of bone arising from its inner surface (fig. 2, IV, PA). The posterior extremity of the nasal shows a semicircular sutural surface (PRF) for the anterior end of the prefrontal. The nasal unites with the superior and inferior premaxillary extensions, and with the frontal and prefrontal. It is entirely excluded from the maxilla by the premaxillary extension, as it is in Trachodon mirabilis,3 Telmatosaurus transylvanicus, Camptosaurus, Claosaurus, and Gryposaurus; this separates the species now described from I. bernissartensis, where it is in relation with the maxilla.4 The nasal is also in union with the maxilla in Scelidosaurus harrisoni 5 and Stegosaurus stenons.

Supraorbital.—The supraorbital (fig. 3, VI, p. 10) is large. It borders the upper anterior half of the boundary of the orbit, and rests upon the external surface of the prefrontal and lachrymal, but more on the latter than on the former. It sends backwards a strong superior process. The inferior half of the bone is remarkably thin. No second supraorbital has been found, and it is possible that only one was present, as in Camptosaurus 6 and in Laosaurus.6

Lachrymal.—The lachrymal (fig. 2, V & VI, p. 6) is a large oblong bone, sending downwards and backwards from its lower posterior angle a stout curved process to meet the anterior extremity of the jugal (fig. 2, V, JP). Its orbital border is very thick, and its anterior border thin. The dorsal border is wide, and forms a ledge for the support of the prefrontal and supraorbital, its inner wall being produced higher than the outer, forming a parapet (fig. 2, VI, S). The upper third of the outer surface is weakly convex and the lower two-thirds flat. The bone is pierced

¹ L. Dollo, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) p. 233.

Id. ibid. vol. iii (1884) pl. vi, fig. 3.
 E. D. Cope, 'American Naturalist' July & Sept. 1883, p. 776 & pl. xvi.

⁴ L. Dollo, op. cit. vol. ii (1883) p. 233.

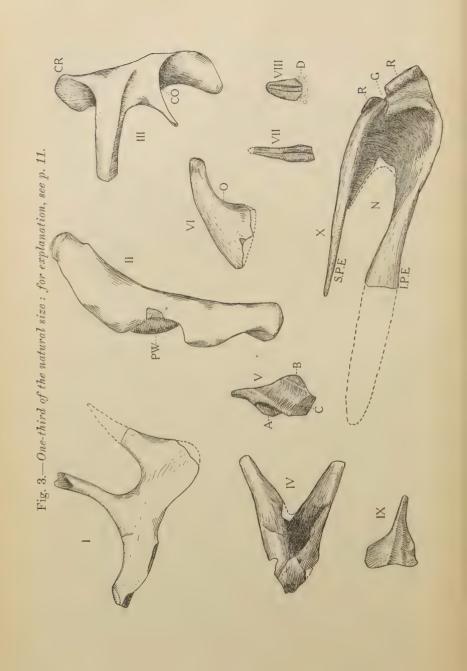
⁵ R. Owen, 'British Fossil Reptilia of the Liassic Formations' Monogr. Palæont. Soc. 1861, p. 9.

⁶ O. C. Marsh, 'The Dinosaurs of North America' U.S. Geol. Surv. 16th Ann. Rep. (1894–95) 1896, pp. 197, 199

longitudinally by a large oval foramen, which traverses the orbital half of the bone pre-postaxially and opens on the interior surface, where its upper and lower borders expand into a large flattened cavity (fig. 2, V, LD, p. 6). The lower border is directed downwards, and dies out towards the anterior extremity. The cavity thus formed doubtless received the naso-lachrymal sac, and the bone comprised a portion of the nasal capsule, which are Crocodilian features. The lachrymal forms the lower anterior border of the orbit and the upper boundary of the antorbital fossa. It articulates with the strong process produced from the upper border of the maxilla by a concave facet (fig. 2, V, MF), and is intercalated between that process and the parapet produced from the outer dorsal border of the maxilla. Its lower anterior angle is wedged in between this parapet and the lower premaxillary extension. The facet for articulation with the latter is on the wall of the lachrymal cavity (fig. 2, V, PF). The lachrymal does not meet the nasal. Its upper border is overlapped by the prefrontal. In a lateral view of the skull the lachrymal appears small, owing to large areas of the bone being overlapped by the supraorbital and the maxilla.

Jugal.—The jugal (fig. 3, I, p. 10) possesses an anterior, a median, and a posterior ray. The two last-named arise from its upper border. The anterior ray is stout, and is directed upwards. The greater part of its anterior extremity forms the articulatory surface for the lower posterior end of the lachrymal, and the smaller portion forms the posterior boundary of the antorbital fossa. On the ventral surface of this ray is an elongated concavity which articulates with the inner surface of the dorsal border of the maxilla. Interior to this surface, and of much greater extent, is a deep, smooth, elongated concavity for the reception of the powerful jugal process of the maxilla. Interior, posterior, and contiguous to this cavity is a wall-like process directed inwards. This process, on its internal extremity, shows a fractured surface. It appears to have lodged against the maxilla. The coronoid process of the mandible occupies the space immediately posterior to it. The median ray is a curved bar directed upwards to meet a process sent down by the postfrontal. The articular surface for the postfrontal process is smooth and deeply hollowed. The preaxial border of this cavity is lower than the postaxial border. Posterior to the median ray the jugal becomes thin and weak. The posterior ray is very thin, and is produced from the hinder end of the upper border. The distal end of this ray has been lost. The ventral border of the jugal is gently arched. The jugal is connected with the maxilla, the lachrymal, the postfrontal, the quadratojugal, and the quadrate. When articulated the bone rests at an angle of 45°, and posteriorly is directed downwards, backwards, and outwards: for, as noted by Prof. Dollo 1 in I. bernissartensis, it is not situated in the same plane as the alveolar border, but at a considerable distance outside.

¹ Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) p. 234.



Quadratojugal.—I identify a small quadrangular bone, with a finger-like extension from its upper angle, as the right quadratojugal (fig. 3, V, p. 10); its fellow is missing. Anteriorly it is overlapped by the jugal (fig. 3, V, B). Posteriorly, the border is expanded, and possesses an elongated groove, apparently for the reception of a portion of the border of the upper outer wing of the quadrate (fig. 3, V, A). The dorsal finger-like extension wraps round the border of that wing, and apparently passes under it at the junction of the ascending process of the jugal with the quadrate. The ventral border (fig. 3, V, C) is overlapped by the lower outer wing of the quadrate.

Squamosal.—The squamosal (fig. 3, III, p. 10) is a moderately stout bone. It sends forward a long process to meet the postfrontal. This process is remarkably thin intero-exteriorly, and shallow dorso-ventrally. Its exterior surface bears a strong, median, longitudinal ridge, which curves downwards near the posterior border of the squamosal. The interior surface of this process is smooth and slightly concave. The squamosal forms almost the entire upper boundary of the infratemporal fossa, occupying the space covered by the bar of the bone (P) 1 figured as a portion of the postfrontal, in the type-skull of *I. bernissartensis*. The hinder dorsal margin of the squamosal is considerably raised (31 mm.) above the plane of the postfrontal process, and forms a striking feature when the skull is seen from the side. This crest (fig. 3, III, CR) is produced inwardly and obliquely forwards as a wing-like wall of bone. On its intero-posterior external surface, near the level of the supratemporal arcade, there is a semicircular concavity for the reception of a process sent out by the parietal. The supratemporal fossa is well exposed on a lateral view of the skull, and more so than in the skull of I. mantelli.2

¹ L. Dollo, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) pl. ix, fig. 1, P.

² Id. ibid. vol. iii (1884) pl. vi, fig. 3.

EXPLANATION OF Fig. 3, p. 10.

I. Exterior aspect of the left jugal.

III. Exterior aspect of the left quadrate. PW, pterygoquadrate wing.
III. Exterior aspect of the left squamosal. CR, squamosal crest; CO, cotylus for the quadrate.

IV. Hinder portion of the right pterygoid.

V. Exterior aspect of the right quadratojugal. A, groove for the reception of the anterior outer border of the quadrate; B, facet articulating with the inner surface of the jugal; C, facet articulating with the inner surface of the lower outer wing of the quadrate.

VI. Exterior aspect of the left supraorbital. O, orbital border.

VII. Exterior aspect of a tooth of the upper jaw.

VIII. Interior aspect of the fifteenth tooth of the lower jaw. D, alveolar parapet.

IX. The right palatine (?).

X. The premaxilla. SPE, superior premaxillary extension; IPE, inferior premaxillary extension; G, groove for the reception of the horny sheath; R, bony ridge; N, external narial opening.

[Broken lines denote missing portions.]

The posterior lower border of the squamosal sends forwards and downwards a process which bounds the upper posterior third of the infratemporal fossa. It overlaps the upper anterior border of the quadrate. The cotylus for the quadrate is very deep and large, with a smooth surface. The squamosal completely caps the head of the quadrate. Its posterior border is prolonged far downwards into a wing, which overlaps the inner surface of the quadrate and, passing beyond and outwards, is considerably exposed on a lateral view of the skull. This process closely resembles that seen in *Trachodon*. A curved ridge on the posterior surface of the squamosal, at the level of the cotylus, apparently denotes the dorsal extent of the paroccipital process.

Quadrate.—The quadrate (fig. 3, II, p. 10) is a long and robust bone. The dorsal half curves backwards, and the ventral half is straight. The lateral surfaces of the dorsal half are flat and converge backwards, meeting and forming a sharp posterior border. Just below the median area the posterior border expands, and continues to do so to the distal end, where it has a transverse diameter of 50 mm. The anterior surface of the quadrate is concave throughout its length. This concavity is increased by the thin, wing-like extensions sent forwards by the anterior inner and outer borders. These wings have their origin near the head of the quadrate, and fade away shortly before the distal articulation. The outer wing is deeply notched in the median region. The wing (fig. 3, II, PW) on the inner border is prolonged much farther forwards than that on the outer border, being prominently visible on a lateral view of the disarticulated bone. This wing is inclined inwards, and not entirely forwards like the outer wing. The inner surface is concave, as in Camptosaurus, as noted by Marsh and quoted by C. W. Gilmore. The length of the quadrate is 185 mm. The head is triangular in cross-section, and comparatively small. The articular surface is convex and smooth. The cotylus of the squamosal is much greater in area, permitting a free movement of the quadrate. The distal articular surface is convex, and has an antero-posterior diameter of 25 mm. and an intero-external diameter of 48 mm. The quadrate articulates with the squamosal, jugal, quadratojugal, pterygoid, surangular, and articular.

Pterygoid. -Only a portion of the right pterygoid (fig. 3, IV, p. 10) was discovered. It comprises the lateral hinder part, which consists of two thin, flat, finger-like processes for articulation with the pterygoid wing of the quadrate. These two processes diverge at a low angle from a thin, concave, and moderately wide plate of bone. Ventrally to this plate the bone is directed downwards and inwards; but, as it is only a fragment, its full extent cannot be deciphered.

 $^{^{1}}$ 'Osteology of the Jurassic Reptile $\it Camptosaurus$, &c.' Proc. U.S. Nat. Mus. vol. xxxvi (1909) p. 212.

Vomer.—The vomer has not been discovered. The converging sutural surfaces already mentioned, as seen on the dorsal surface of the anterior ends of the maxillæ, suggest that the anterior extremity of the vomer was triangular in shape. The extreme narrowness of the space between the maxillary walls proves that its posterior extension could have been no more than a thin bar of bone, and the absence of any sutural surface manifests that no further union with the maxillæ took place.

Mandible.

Each ramus has a gentle, sigmoid curve from the symphysis to its posterior extremity, as in Scelidosaurus, and measures 413 mm. in length. The symphysis (fig. 4, I, S, p. 14) is 46 mm. long, and is inclined backwards and downwards in so marked a degree that the ventral border is much exposed on a lateral view, as in I. mantelli, and much more than in I. bernissartensis. Gilmore, referring to Hulke's description of the anterior end of the mandible of Hypsilophodon as having a 'spout-like symphysial end', remarks that this 'aptly describes this region in Camptosaurus', and it applies no less forcibly to this Iguanodon. The dorsal borders of the rami, from above the posterior end of the symphysis to its anterior termination, slope abruptly downwards. Posteriorly to this they are straight. The ventral borders are concave.

Predentary.—The predentary bone has not been found.

Dentary.—The dentary (fig. 4, I & V, D, p. 14) is very powerful. It forms the whole of the ramus anterior to the coronoid process, excepting thin anterior extensions of the angular and the splenial. The external surface in the median region is convex throughout its length and slightly concave dorsally, near the coronoid process. The dorsal border in the area occupied by the teeth is sharply crenated. The alveolar border is horizontal. It is inclined inwards for two-thirds of its length, and curves outwards to the coronoid process for the remaining third. In the median area of the dentary there is a pronounced swelling of the inner walls.

On the external surface of the dentary, near the dorsal border, a series of foramina occur from the coronoid process to the tip of the mandible. The largest is situated at the anterior end, near the symphysis, as in *Camptosaurus*. The interior surface of the dentary is strongly concave at the symphysial end, with the lower border produced downwards and inwards. The Meckelian groove, very shallow at its beginning on the ventral border, near the hinder end of the symphysis, gradually expands and deepens posteriorly, until it is only bounded outwards by the exterior dentary wall (fig. 4, V, p. 14).

R. Owen, 'Reptilia of the British Liassic Formations' Monogr. Palæont.
 Soc. 1861, pp. 12-13.
 Proc. U.S. Nat. Mus. vol. xxxvi (1909) p. 219.

Fig. 4.—One-third of the natural size: for explanation, see p. 15.

A fracture of the left ramus, at the 9th alveolus from the anterior end, shows a section of solid bone, except for a small circular canal. At the level of the base of the teeth the inner surface of the dentary loses its smoothness, and the texture of the bone changes, becoming less dense and feebly rugose, very much thinner, and forming a continuous alveolar parapet. The latter is 13 mm. high at the 6th tooth, and 23 mm. high at the 15th tooth, from the anterior end. At its line of junction with the main body of the dentary it is pierced by a longitudinal row of foramina, which are divided by narrow grooved buttresses of bone, resembling those seen on the inner surface of the maxillæ. An artery evidently traversed this groove, sending branches through the foramina to the bases of the teeth. Neither this inner alveolar parapet is seen, nor are the foramina exhibited in Prof. Dollo's I figure of the mandible of I. bernissartensis, nor does he refer to either. Again, it is not exhibited in Owen's 2 figure of the dentary part of the right branch of the lower jaw of a young Iquanodon. Mantell³ refers to 'a moderately strong plate or wall, which must originally have almost equalled the outer parapet in height', in the lower jaw of an Iguanodon discovered by the late Capt. Brickenden. In a mandible of Hypsilophodon foxii in my collection the same feature occurs: here the inner alveolar parapet is as high as the outer. That an inner alveolar parapet also occurs in Camptosaurus appears certain, for a part of the wall and a few of the foramina are to be seen in the inner side of a portion of the mandibular ramus which Owen 4 described as a young Iquanodon, but which, from the teeth and the number of the alveoli, evidently

¹ Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) pl. ix, fig. 3.

² 'Reptilia of the Wealden & Purbeck Formations' Monogr. Palæont. Soc. pt. 2 (1855) pl. xi, fig. 2.

3 'Petrifactions & their Teachings' 1851, p. 244.

4 R. Owen, op. cit. Suppl. iii. 1864, pl. x.

EXPLANATION OF FIG. 4, p. 14.

I. Interior aspect of the left mandible restored from the bones discovered. C, coronoid process; SA, surangular; AR, articular; AN, angular; D, dentary; S, symphysis; AL, alveoli; AP, alveolar parapet; F, series of foramina; PA, facet for the prearticular; MG, Meckelian groove, covered in life by the splenial, which passed on to the ventral border of the angular at P; SAF, surangular foramen.

II. Interior aspect of the left coronoid process; TP, tongue-like process, between which and the outer coronoid wall the surangular is inserted; W, wing-like process overlapping the outer surface of the surangular; S, surfaces uniting with the dentary; A, the last two alveoli.

III. Exterior aspect of the left coronoid process. TP, tongue-like process

IV. Exterior aspect of the right angular. DF, facet for the posterior extension of the dentary; P, facet for the splenial.

V. Transverse section of the right dentary at the 18th alveolus. A, alveolus; D, dentary; M, Meckelian cavity.
VI. Exterior aspect of the left thyrohyal.

Broken lines denote missing portions.

belongs to Camptosaurus. The inner alveolar wall was preserved in both rami of the specimen now described, but was removed from the left ramus to expose the successional teeth, for all but one of the functional teeth had dropped from the jaws. There are 9 of these teeth in the right, and 14 in the left, ramus. There are 22 alveoli, all separated by strong bony partitions, which is one more than in I. bernissartensis. The inner alveolar parapet for the last two teeth is formed by the coronoid. Each successional tooth everlaps the two septa bordering the alveolus which its fang would have eventually occupied. The teeth decrease in size towards each extremity of the alveolar border. The dentaries are in relation with the coronoid, the angular, the surangular, the prearticular (?), and the splenial (?). Externally, the dentaries overlap the angular by a pointed extension.

Coronoid process .- The left coronoid (fig. 4, II & III, p. 14) has parted from the dentary along what has the appearance of a suture; but, as there is no sign of a suture visible on the exterior of the right mandible, where the coronoid appears fused to its ramus, and as its existence as a separate element is unknown in the Dinosaurian mandible, it must be regarded as an accidental fracture. It is a fairly broad stout plate of bone, constricted antero-posteriorly in its median region. It is much thickened by the lower anterior border being produced into a strong buttress of bone directed obliquely downwards. On the anterior face of this buttress (fig. 4, II, S) is a broad, apparently sutural surface, which unites for three-quarters of its length with the dentary, from the exterior surface of that bone to below, and exterior to, the 19th and 20th alveoli. The remaining quarter of its length forms the exterior parapet of the last two alveoli (fig. 4, II, A). From the posterior median surface of this buttress is produced upwards and backwards a tongue-like process (fig. 4, ÎI, TP), which overlaps the interior surface of the surangular. Superiorly to this buttress arises the coronoid apophysis. The exterior, posterior, lower border of the coronoid sends backwards a wing of bone (fig. 4, II, W), the lower border of which unites with the exterior wall of the dentary. The greater portion of this wing overlaps the exterior surface of the surangular, and, with a small moiety of its lower angle, overlaps the angular.

Surangular.—The dorsal border of the surangular (fig. 2, III, p. 6) exhibits two concavities of about equal extent, divided by a ridge. The dorsal border in the posterior concavity is much expanded intero-exteriorly, to form the outer half of the quadrate articulation; the ventral border is convex. The hinder end is strongly inflected, wrapping round the articular and extending beyond it. The anterior half of the bone is a thin wing-like expansion, slightly convex exteriorly and concave interiorly. Near the anterior dorsal border is a large oval foramen, visible exteriorly when the surangular is articulated. This foramen occurs in

I. bernissartensis, although according to Prof. Dollo's ligure the foramen is circular and much more ventral, if that figure depicts the true position of the bone, which is denoted as the articular, but it is, as Gilmore suggests, doubtless the surangular.2 The bone shown in Dollo's figure is apparently distorted and displaced. The posterior interior surface of the surangular is deeply grooved for the reception of the articular. The ventral border articulates with the angular. The forward extremity overlaps the angular to a small extent. It exhibits on its interior surface a crescentic sutural surface (fig. 2, III. AF, p. 6). Above this surface is a larger sutural facet (PA) of the same shape, but of much greater extent antero-posteriorly. This facet I take to be the anterior articulation of a prearticular bone, which unfortunately has not been discovered. The surangular unites with the coronoid, angular, articular, and prearticular (?); but it does not meet the dentary, which is contrary to what has been observed by Gilmore in Camptosaurus.3

Angular.—The angular (fig. 4, IV, p. 14) is a long, thin bone, 195 mm. long, vertically expanded in the median area, and tapering towards each extremity. The posterior end of the bone is strongly incurved, corresponding to the inward bend of the hinder end of the surangular. The outer surface is gently convex, except where it is overlapped by the posterior extremity of the dentary, which area is flat and feebly striated (fig. 4, IV, DF). The ventral border exhibits a strongly-marked sutural surface or the anterior two-thirds of its length. This surface, partly visible externally (fig. 4, IV, P), was doubtless occupied by a splint from the splenial. The angular is in connexion with the dentary, coronoid, splenial, surangular, articular, and prearticular (?); and it is well exposed on the exterior surface of the ramus.

Articular.—The articular (fig. 2, III, A, p. 6) is a small, stout bone. In lateral aspect it is crescentic in form, the upper border being concave and the lower convex. Seen from behind, it is wedge-shaped. The expanded upper border is concave, and forms the inner half of the quadrate articular surface. The transverse diameter is 19 mm. The ventral border is a sharp edge. The outer surface is convex, for articulation with the concave inner surface of the surangular. The expanded anterior end of the articular exhibits a strongly rugose and convex sutural surface, apparently for union with the prearticular. The articular is in relation with the quadrate, surangular, and prearticular (?).

Prearticular.—That there was a prearticular bone seems clear from the presence of an anterior sutural surface or the articular and a crescentic facet on the lower anterior and interior surface

¹ u ll. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) pl. ix, ng 4.

Proc. U.S. Nat. Mus. vol. xxxvi (1909) p. 221.
 Ibid. p. 220.

Q. J. G. S. No. 321.

of the surangular, immediately above the articular facet for the angular. It also appears from the direction that it must have taken to articulate with these surfaces, that the Meckelian fossa was extensive, and that the upper anterior extremity of the prearticular was intercalated between the coronoid, the surangular, and angular. It must have been an elongated bone like that seen in Camptosaurus. C. W. Gilmore suggests that the small bone marked 'a' in fig. 3, pl. ix of Prof. Dollo's 4th Note is really the prearticular, and not the surangular.

Splenial.—No portion of the splenial has been found, but here again the sutural surfaces on the dentary and the angular give a clue to its extent and form. The forward extension appears to have reached the 11th alveolus of the mandible, counting from the anterior end, which would be four teeth farther forward than in I. bernissartensis, as determined by Dollo. An anterior fingerlike extension probably covered the Meckelian groove still farther, for the anterior end of the sutural facet curves downwards and forwards into that groove. The backward extension along the ventral border of the angular was probably exposed on a lateral view of the ramus, as in Camptosaurus and Stegosaurus. Its posterior dorsal extent is not so apparent. There is some appearance of a sutural connexion on the posterior surface of the dentary, and, if such it be, it nearly reached the hinder extremity of the alveolar border. That it had no union with the coronoid is quite clear, for that bone unites with the inner substance of the dentary, below the outer alveolar wall. In Camptosaurus the splenial meets the coronoid.2

Hyoid.—The left thyrohyal (fig. 4, VI, p. 14) has been preserved. It is a short, fairly stout, laterally compressed, curved bar of bone, gradually tapering to its distal extremity. Its proximal end is expanded intero-exteriorly.

The Fossæ of the Skull.

Anterior nares.—The anterior narial opening (fig. 1, NAR, p. 2) is large and elongate-oval. It is 147 mm. long, and near the anterior boundary 43 mm. deep. The narial openings are bounded by the premaxillæ and their upper and lower extensions, and by the nasals.

Antorbital fossa.—The antorbital fossa (fig. 1, AF) is very small. It is bounded above by the lachrymal, in front and below by the maxilla, and behind by the jugal. This arrangement is similar to that seen in Gilmore's restored figure of the skull of Camptosaurus, although he says that 'there are no preorbital

² Ibid. p. 222.

¹ Proc. U.S. Nat. Mus. vol. xxxvi (1909) p. 221.

³ Ibid. fig. 2, p. 205 & p. 216.

fossæ.' Prof. Dollo does not mention the jugal as forming a portion of the boundary of the autorbital fossa in *I. bernissartensis*, and remarks that the prefrontals appear to form a part of the border. In the specimen here described the latter bones are far removed from the autorbital fossa.

Orbit.—The orbit (fig. 1, 0, p. 2) is large and subcircular. Its vertical diameter=72 mm. and its horizontal diameter=82 mm. The orbit is bounded in front by the lachrymal and supraorbital, above by the supraorbital and postfrontal, behind by the postfronto-jugal processes, and below by the jugal. The orbits do not look directly outwards, but obliquely forwards, through the broadening of the skull by the outward divergence of the upper and lower areades.

Supraorbital fossa.—This was probably present.

Infratemporal fossa.—The infratemporal fossa (fig. 1, ITF, p. 2) is pear-shaped, the broad end being uppermost. The greatest dorso-ventral diameter=114 mm. It is bounded in front by the jugo-postfrontal processes, above by the postfrontal and squamosal processes, and behind by the squamosal and jugal processes and the quadrate.

Teeth.

Upper Teeth.—The only functional upper tooth (fig. 3, VII, p. 10) found was attached to a limb-bone. It belongs to the right maxilla. The length of this tooth, which is well worn by use, is 54 mm., of which the fang comprises 32 mm. It is strongly curved, the concavity being on the inner side. A comparison with the three small successional teeth present in the maxillæ shows that it was originally spatulate in form. The anterior border is much thickened and slightly convex, with a longitudinal concavity passing on to the fang. The outer margin of this border bears notched serrations moderately developed. These serrations are continued farther towards the fang than those on the posterior border. Below the serrations on both borders the outer margins of the tooth are feebly striated longitudinally. The posterior border is sharp. There is one highly-developed primary ridge on the exterior surface, near the posterior border. It is 3 mm. high and 4 mm. wide in the median region. Dorsally, it curves gently towards the posterior border. On either side of this ridge is a longitudinal valley, the anterior being the wider. There are three incipient secondary ridges present in the anterior valley. Two of these arise at the base of the crown, separated by a narrow valley. They converge towards each other, coalesce, and end in the median region of the crown. Between the point where they unite and the primary ridge, the third ridge originates, and continues to the apex of the tooth. The inner surface of the tooth is convex near the summit; but ventrally the interior half becomes flat, through the thickening of the anterior border. The fang is long

and tapering, the anterior border is longitudinally concave, and the posterior transversely convex. The outer surface exhibits feeble longitudinal ridges and grooves.

Lower Teeth.—The lower teeth (fig. 3, VIII, p. 10) are strongly curved, the concavity being exterior. They are compressed intero-exteriorly and spatulate, some of them being more acuminate than others. The marginal serrations are more fully developed than those of the upper teeth, and placed farther apart one from the other. The serrations also are all notched, and are continued farther down the margins than in the upper teeth. In the median third of each tooth there are a primary and a secondary longitudinal ridge, the primary being the posterior and the more developed, but not comparing in height or width with the pronounced primary ridge of the upper teeth. Both these ridges are straight and parallel, from the apex to the base of the crown. There are three longitudinal valleys. Extremely-shallow transverse flutings are visible in the valleys of some of the teeth. Only on a successional tooth, occupying the 8th alveolus from the anterior end of the alveolar border, is there a tertiary ridge visible. On this tooth near the apex is a weak short ridge, immediately posterior to the secondary ridge.

Vertebral Column.

Th vertebral formula is :--

Cervicals, eleven.
Dorsolumbars, seventeen.
Sacrals, six.
Caudals, twelve (the remainder missing).

The number of presacral vertebræ is the same as in I. mantelli1 and I. bernissartensis2: that is 28; but in the specimen here described one more is assigned to the cervical series, and one less to the dorsolumbar, than has been determined by Prof. Dollo in hose species. The 11th vertebra has the parapophysis clearly below the neurocentral suture, whereas in the 12th it is above, at the base of the diapophysis; and its serial position is certain, for the vertebra were fixed by matrix in consecutive series. There is no gradual transition, but an abrupt change of the position of the parapophysis. All the cervicals posterior to the axis are opisthoccelous. Each has a large anterior ball and a deep posterior cup. The central area of the ball is slightly flattened, with a small shallow pit in the centre, and is inclined upwards and backwards. The lower articular surface of the ball has a greater pre-postaxial extent than the upper, and correspondingly the lower lip of the posterior cup is prolonged posteriorly farther than the upper, the effect being that, when the vertebræ are in articulation, the neck is naturally curved, the convexity being ventral. The first three

L. Dollo, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) p. 243.
 Id. ibid. vol. iii (1884) p. 130.

dorsals are plano-concave, and the 4th to the 12th amphicolous; but in all the concavity is very shallow. The centrum of the 13th dorsal is plano-concave, as are all the centra from here to the penultimate dorsolumbar, but with the concavity gradually deepening in each following centrum. The dorsolumbar, sacral, and early caudal vertebræ are braced by ossified tendons.

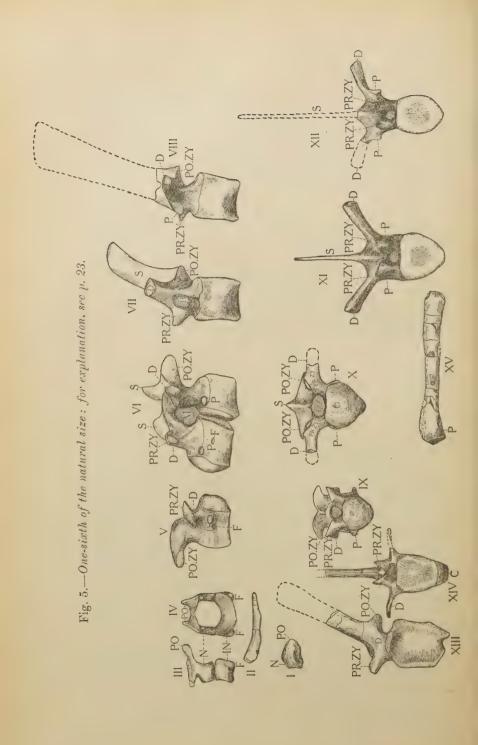
Pro-atlas.—The pro-atlas (fig. 5, I, p. 22) is a small, short, wedge-shaped bone, flattened transversely. The ventral border is much expanded, and slightly concave. All the other borders are sharp.

Atlas.—The atlas (fig. 5, III & IV, p. 22), as preserved, comprises three separate pieces—two neurocentra and an intercentrum. The odontoid was not found. The neurocentra dorsally are produced inwards into slightly arched plates, which meet in the median line, where their borders are weakly raised. The postzygapophyses (fig. 5, III & IV, PO) originate from the entire posterior borders of the neural platforms, and are prolonged backwards and upwards as strong processes, wider than deep. They gradually taper to their distal extremities, where they become deeper than wide, and bear (on their anterior surfaces) articular facets which look inwards. The pedicles are deeply notched on their anterior borders, and slightly concave on their posterior borders. Their bases are thick intero-externally. The anterior borders of the neurocentra are weakly concave, and form the dorsal articular surface for the occipital condyle; their ventral surfaces rest upon the intercentrum. The intercentrum is crescentic. The ends of the horns of the crescent are obtuse, and slightly rounded. They carry the bases of the neurocentra. The anterior surface is concave, with the ventral border produced much farther forward than the dorsal, forming a lip which underlies the occipital condyle. The posterior surface is convex dorso-ventrally in the central region, and flat at the outer extremities, where the bone is much deepened by downward directed processes produced from its ventral surface. These processes bear facets (fig. 5, III & IV, F) for the attachment of the ribs of the atlas. The posterior border is slightly concave transversely. Ventrally the atlas is transversely oblong, the anterior half is convex, and the posterior half is inclined upwards and backwards, between the raised bosses of bone, for the support of the atlas ribs.

The axis is missing.

Third cervical.—All but the postzygapophyses and the crown of the arch of the third cervical is lost.

Fourth cervical.—The pre-postaxial extent of the neural arch (fig. 5, V) is less than that of the centrum, exposing anteriorly the floor of the neural canal. The neural arch is inclined upwards and backwards, and raised in the median line into a weak spine, which soon bifurcates into two divergent angulated ridges. These



gradually become rounded and confluent with the convex dorsal borders of the postzygapophyses. The latter are very long stout processes, springing from the neural arch almost horizontally, and curving outwards. The proximal halves of their ventral borders and the postaxial borders of the pedicles of the arch are much excavated, and, as similar features are found in the preaxial borders of the prezygapophyses and pedicles of the following vertebra, there is formed a large intervertebral foramen. The posterior halves of the ventral surfaces of the postzygapophyses bear large, oval, articular facets for articulation with the prezygapophyses of the fifth cervical. These facets look downwards and outwards. The prezygapophyses (fig. 5, V, PRZY) arise partly from the arch and partly from its pedicles. They are stout processes directed outwards and forwards. The articular facets look upwards, inwards, and backwards. The diapophyses (fig. 5, V & X, D) jut out from the base of the outer surface of the prezygapophyses as short feeble tubercles. The tubercular facet looks downwards and outwards. Below the diapophyses the neurapophyses are depressed. This depression is intensified by the parapophyses (fig. 5, X, P) which, arising just below the neurocentral sutures, near the anterior articular border, are produced outwards into strong wide processes: these have, on their outer extremity, an articular facet for the capitulum of the cervical rib. Ventrally to the parapophyses the centrum is compressed, especially forwards, to such an extent that the ventral border becomes a rounded keel which broadens posteriorly, where it has a very rugose surface. A foramen (fig. 5, V, F) occurs in the median lateral region of the centrum near and below the parapophyses. A similar

EXPLANATION OF Fig. 5, p. 22.

- I. Exterior aspect of the left pro-atlas. N, neurapophysis; PO, postzygapophysis.
- II. Exterior aspect of the left rib of the atlas.
- III. Left lateral aspect of the atlas. N, neurocentrum; IN, intercentrum; PO, postzygapophysis; F, facet for rib.
- IV. Anterior aspect of the atlas. Same lettering as in III.
- V. Right lateral aspect of the fourth cervical vertebra. PRZY, prezygapophysis; POZY, postzygapophysis; D, diapophysis; P, parapophysis; F, foramen.
- VI. Left lateral aspect of the last cervical and the first dorsal vertebra. S, neural spine; M, matrix; other lettering as in V.
- VII. Left lateral aspect of the 4th dorsal vertebra. Same lettering as in VI.
- VIII. Left lateral aspect of the 10th dorsal vertebra. Same lettering as in V.
 - IX. Anterior aspect of the 4th cervical vertebra. Same lettering as in V.
 - X. Anterior aspect of the last cervical vertebra. Same lettering as in VI. XI. Anterior aspect of the 4th dorsal vertebra. Same lettering as in VI.
- XII. Anterior aspect of the 10th dorsal vertebra. Same lettering.
- XIII. Left lateral aspect of the 9th caudal vertebra. Same lettering.
- XIV. Anterior aspect of the same vertebra. Same lettering. C, chevron
- XV. Lateral aspect of the eighth chevron. P, proximal end. [Broken lines denote missing portions.]

foramen is to be observed from the 4th to the last cervical, but is not to be found on the succeeding dorsal vertebræ. J. W. Hulke mentions a large foramen as occurring in the fourth cervical of Camptosaurus prestwichii.

Changes in form of the cervical vertebræ.-From an examination of the whole cervical series the weak crest in the median line of the neural arch of the 4th cervical is proved to be the incipient neural spine. On the 11th cervical (fig. 5, (, S, p. 22) the crest has become much expanded transversely, and, at its hinder end, elevated 23 mm. above the neural arch. The lengthening of the spine takes place at this extremity by the nion and upward production of the two divergent angulated edges found on the neural arch of the anterior cervicals. There is a remarkable shortening of the platform of the neural arch of the 9th cervical, which is not to be observed in any other vertebra of the series. The length is only 28 mm., and the neural spine anteriorly overhangs the neural canal. The effect of this is that 26 mm. of the anterior neural floor is exposed, on a vertical view of the disarticulated vertebra. In all the cervical vertebræ after the 5th the deeply-cupped, posterior, articular surface of the preceding vertebra permits the entrance of the ball of the following centrum to such an extent that the anterior border of the neural arch of that vertebra enters well into the cleft formed by the divergent postzygapophyses. Thus the vertebræ are interlocked, but with perfect freedom of movement.

The neural arch becomes more elevated posteriorly from the

4th to the 9th cervical.

A foramen into the neural cavity at the bottom of a deep pit, below the point of coalescence of the postzygapophyses, is seen in the 7th, 9th, and 10th cervical vertebræ. The other cervicals have this region so covered by matrix which cannot be removed that it is impossible to determine whether it is continued throughout the series. A similar foramen is found in *Camptosaurus*.²

The postzygapophyses increase in length to the 9th cervical.

In the next two vertebræ they are much shortened.

The width between the tubercular facets of the diapophyses gradually increases postaxially throughout the cervical series.

The width between the capitular facet of the parapophyses is great in the 7th and 8th cervicals, and then rapidly narrows. In the fourth and fifth the parapophysis is a long stout process; in the last cervical it is a slightly raised protuberance. Thus, while there is still a strong transverse compression of the body of the centrum, it is not so marked a feature on a lateral view, by reason of the retraction of the parapophysial process.³

The neurocentral suture is not traceable in any but the last

¹ Q. J. G. S. vol. xxxvi (1880) p. 441.

² C. W. Gilmore, Proc. U.S. Nat. Mus. vol. xxxvi (1909) p. 230.

³ In the future study of this specimen it should be noted that portions of the heads of several of the cervical ribs are still attached to the parapophyses.

cervical, where it bisects transversely the parapophysial facets, near their upper border, as in the same vertebra of the Crocodile.\(^{12}\)

The neural canal is subcircular and large throughout the series. There is a gradual increase in the length of the centra until the 9th, which is the longest. The 10th and 11th are shorter than the 9th. The transverse diameter of the posterior ends gradually increases throughout the series.

Dorsolumbar vertebræ.—The neural spine of the first dorsal (fig. 5, VI, S) is 32 mm. high, is short and claw-like in form, with the convex border placed anteriorly. In the fourth dorsal (fig. 5, VII, S) it has become a thin plate of bone 114 mm. high, and 40 mm. wide pre-postaxially, near its summit. The remainder of the spines of the vertebral column have all lost more or less of their length. The neural arches of the first and second dorsals are still as much inclined upwards and backwards as in the last cervical; but in the third dorsal the arch becomes horizontal. In the first dorsal the facets of the prezygapophyses look inwards, upwards, and backwards. The postzygapophyses are shorter than in the last cervical. From the exterior borders of the prezygapophyses, and immediately exterior to their facets, are produced stout long diapophyses, but slightly inclined upwards. tubercular facets placed on the anterior halves of their extremities look forwards and downwards. The angulated ventral borders of the diapophyses are continued downwards and forwards as raised buttresses, across the anterior outer surface of the pedicles, to the neurocentral sutures. In the last cervical, in the place of this buttress, is a deep depression, and thus there is a marked difference in this region between the two vertebræ. An abrupt change has taken place, as in the same vertebra of Crocodilus:

'there is no longer a capitular distinct from a tubercular process, but one long "transverse process" takes the place of both.' (Op. cit. p. 216.)

Just above the neurocentral sutures are circular, concave, capitular facets. The sides of the centrum in its lower half are concave pre-postaxially and compressed, as in the cervicals, producing a somewhat less rounded ventral keel. The anterior articular surface is plane, with a narrow, convex, articular border 8 mm. wide. A similar characteristic is also found in the corresponding vertebra of *Camptosaurus*, as mentioned by C. W. Gilmore, who quotes Marsh as having noticed a similar feature in *Ceratosaurus*. The posterior articular surface is concave.

Second dorsal.—In the second dorsal the neural spine has increased in length, and is wider pre-postaxially. A great reduction in the length of the postzygapophyses and a lessening of their dimensions have taken place. The capitular facets have risen on the diapophyses, and have become elongate-oval and larger. The

T. H. Huxley, 'Anatomy of Vertebrate Animals' 1871, pp. 215, 216.
 Proc. U.S. Nat. Mus. vol. xxxvi (1909) p. 281.

anterior articular surface of the centrum is similar to that of the first dorsal, but with the articular border narrower. The posterior articular surface is nearly plane.

Third dorsal.—In this vertebra the neural spine has been still further lengthened, and the postzygapophyses shortened. Here they have reached their greatest retraction, and no other change takes place throughout the series, except an increase in dimensions proportional to the additional heaviness of the vertebræ, as the lumbar region is reached. Throughout the vertebral column to the sacrum both the pre- and postzygapophyses overlap the articular surfaces of the centra that carry them. The articular facets of the prezygapophyses are no longer immediately interior to the diapophyses, but are borne on stout processes directed preaxially, and are visible on a lateral view. The capitular facets have still further risen on the diapophyses. A great change has taken place in the articular surfaces of the centrum. They are

both now slightly concave.

In all the dorsolumbar vertebræ the neural spine lies above the posterior half of the centrum, with a slight backward inclination. The diapophyses in all the dorsolumbar vertebræ are long and stout. The most robust are those borne by the 3rd, 4th, 5th, 6th, 7th, 8th, 9th, and 10th vertebræ. Those of the 1st and 2nd vertebræ are directed horizontally outwards. In the 3rd they are inclined slightly upwards. In the 5th, 6th, 7th, and 8th they have reached a high angle with a slight postaxial direction; they are in fact as highly elevated—at an angle of 45° to the vertical axes of the centra—as in Trachodon, Stegosaurus, and Triceratops. In the 9th the inclination is less, and in the 13th the diapophyses are almost horizontal and the backward inclination is no longer found. They begin instead to curve in a preaxial direction, so that the tubercular facets look forwards. This curve is intensified in each succeeding vertebra to the sacrolumbar vertebra where the curve is greatest (fig. 10, VI, p. 46). This change in direction is a remarkable feature, and is not due to post-mortem distortion. From the 3rd dorsal the base of the diapophyses is considerably widened, sending out laminæ from the pre-postaxial borders, which at the base meet the pre-postzygapophyses. Under the postaxial laminæ, at the base of the transverse processes, are pit-like depressions, which in the last dorsolumbar or sacrodorsal are very deep The oval, concave, capitular facets reach the preaxial border on the 7th dorsal. On the 8th they are placed much higher; the long axes of the facets are inclined backwards, and the upper portions look forwards. They form a step on the transverse processes. All the dorsolumbar transverse processes carry ribs, and in the penultimate there are fairly large capitular and tubercular facets; but in the sacrolumbar vertebra the rib is singleheaded and free, articulating with the extremity of the transverse Prof. L. Dollo says that, in I. bernissartensis, this

¹ Bull, Mus. Roy. Hist, Nat. Belg. vol. ii (1883) p. 245.

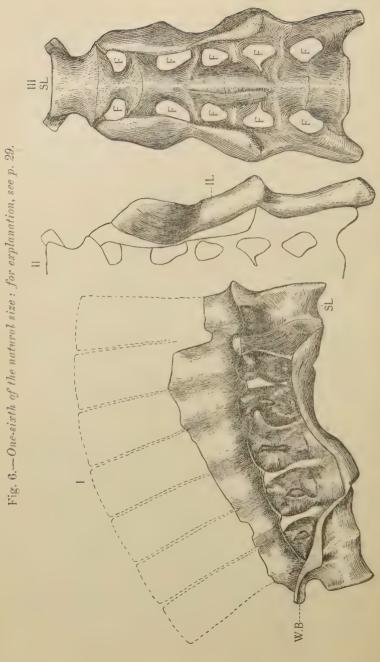
vertebra does not carry a rib. The last lumbar (sacrolumbar) is the heaviest vertebra of the column. Its ventral surface is subquadrate in outline, concave pre-postaxially and broadly convex transversely, with an incipient carina. The posterior articular end is much expanded, and is fused to the anterior extremity of the first sacral.

The intervertebral foramina, which at the 2nd and 3rd dorsal are subcircular, as in the cervicals, become elongate-oval but subcircular again between the 8th and 9th dorsals, and continue so to the sacrum.

The articular surfaces of the centra are concave from the 3rd dorsal to the 12th. In the 12th vertebra the anterior concavity is greater than in the posterior. In the 13th the anterior articular surface is plane, and the posterior concavity deepens, until in the penultimate lumbar it is well cupped. The anterior articular surface of the 4th dorsal vertebra is of a cordate form, and in the 10th dorsal, through a lengthening of the vertical diameter, it is of a truncated oval contour. An angulated keel is found on the ventral border throughout the dorsal series, although weakly developed on the last two dorsolumbars. From the 10th dorsal the keel is more fully developed on the anterior half of each centrum. In the median region, above the compression of the centra to form the ventral keel, the sides of the centra are flat vertically and concave pre-postaxially by the raising of the articular borders. All of these centra are much narrower transversely than in the cervicals. From the 13th vertebra the dorsals rapidly increase in dimensions, and the sides of the centra become strongly convex. The length of the centra of the dorsals increases from the 1st to the 7th and 8th, which are equal in length, and decreases from the 8th to the 15th. The latter is the shortest vertebra in the column between the 3rd cervical and the sacrum. The 15th dorsal is also the shortest in Camptosaurus. The next two vertebræ are longer than the 15th.

Sacrum.—The sacrum (fig. 6, I & III, p. 28) comprises six completely fused vertebræ. The distal ends of the neural spines are lost; their bases are anchylosed one to the other, forming a solid vertical wall throughout the series. The neural arch of each vertebra is advanced to rest upon the preceding centrum. The neural arches of the last lumbar and first sacral vertebræ, as shown by a section exposed by a vertical fracture, are very robust, consisting of a transversely and vertically swollen mass of bone overlying the neural cavity. This swelling gradually lessens in each succeeding vertebra to the 6th. The diapophyses spring from the point of greatest thickness, and are directed outwards. Proximally, the pre-postaxial margins of the diapophyses are expanded, and form stout laminæ which overlap deep and wide pits on the pedicles of the neural arch, except in the case of the preaxial side of the first diapophyses and the postaxial side of

¹ C. W. Gilmore, Proc. U.S. Nat. Mus. vol. xxxvi (1909) p. 234.



the last, where there are no pits. The diapophyses are connected with the sacral ribs by a thick vertical wall of bone (fig. 6, I, p. 28), which on the 1st and 2nd sacral vertebræ arises from a high and heavy buttress developed on the anterior lateral surface of the centra, in the 3rd, 4th, and 5th intervertebrally, and in the 6th from the median lateral region of the centrum. The 3rd sacral rib is the shortest, and the 6th the longest. The distal ends of the sacral ribs are expanded both dorso-ventrally and prepostaxially, coalescing with the preceding and following ribs, thus forming a continuous wide band, with a sigmoidal curve, from the anterior border of the 1st to the posterior border of the 6th vertebra. This 'sacricostal yoke' provides with its whole length a support for the ilium. It forms the external boundary of five lurge foramina (fig. 6, III, F, p. 28). The articular surface from the 1st to the 5th vertebra looks outwards and downwards, and is considerably arched. From the 5th to the 6th vertebra it looks outwards only, and is inclined upwards to such a degree that at its termination it lies above the plane of the neural arch of the last sacral vertebra.

The sacrum is narrower at the preaxial than at the postaxial end. The narrowest portion is immediately over the axis of the acetabulum, at the union of the second and third sacral centra.

Neural foramina occur at the level of the neural canal on the lateral wall of the fused vertebræ.

The body of the centrum of the first sacral is very much constricted, more so than any other of the sacral centra, the transverse diameter in the median region being half that of the last lumbar. The posterior extremity is narrower than the anterior, and is decidedly crescentic, the horns being preaxially directed. The ventral surface is weakly concave pre-postaxially, and nearly flat transversely. The head of the left femur was attached by pyrites to the ventral surfaces of the 2nd and 3rd vertebræ; and, on the former being detached, portions of those surfaces were torn away, but not sufficiently to prevent their true form from being made out. The anterior extremity of the 2nd sacral is fused with the distal expansion of the 1st and 2nd sacral ribs. The posterior end is entirely free from the distal expansion on the 3rd sacral rib. A similar feature is found in the remaining sacrals. The ventral surface of the 2nd sacral is concave pre-postaxially, and

EXPLANATION OF FIG. 6, p. 28.

I. Right lateral aspect of the sacrum. SL, sacrolumbar vertebra; WB, wing of bone, the outer border of which is applied to the interior wall of the post-acetabular projection of the ilium. The extreme outer portions of the 2nd, 4th, and 5th transverse processes have been broken off, and are shown in the figure unshaded.

II. Left side of the ventral aspect of the sacrum (unshaded), with the ilium in articulation.

III. Ventral aspect of the sacrum; restored from both sides. SL, sacrolumbar; F, foramina.
[Broken lines denote missing portions.]

convex transversely. The centrum of the 3rd sacral swells very much postaxially, becoming cylindroid. Laterally, it is slightly constricted. The ventral surface is traversed longitudinally by a deep and wide groove, which is continued on to the 4th, and terminates on reaching the 5th sacral. The 4th sacral is also cylindroid in form, but tapers in an opposite direction to that of the 3rd sacral (that is, postaxially) with a sudden expansion of its articular borders on its union with the 5th sacral. The 5th and 6th centra are the largest of the sacral series. Pre-postaxially, they are weakly concave, and broadly rounded and expanded transversely. There is no median groove, as in the 3rd and 4th centra. A slight carina occurs on the 6th.

The expansion of the sacral ribs of the 5th and 6th vertebræ is lost on the right side, but in the figure it has been restored from

that of the left side.

Caudal vertebræ.—Only twelve caudal vertebræ have been discovered; ten of these are consecutive, and bear transverse processes. With the exception of the 1st, all the centra have well-defined anterior and posterior chevron-facets. The chevrons articulate intervertebrally. The 1st centrum of the series has only a postaxial chevron-facet, and thus (by analogy with I. bernissartensis) is evidently the 3rd vertebra of the tail. The two remaining vertebræ have no neural spines. In I. bernissartensis 2 the spine has totally disappeared in the 27th caudal. The serial position of the larger of these two vertebræ, from its dimensions, seems to be mid-way between the 27th caudal vertebra and the tip of the tail, and that of the smaller vertebra, from its size and character, to be very near the end of the caudal series. The 7th vertebra (fig. 5, XIII, p. 22) of the above chain, that is, the 9th behind the sacrum, may be taken as a type of the early caudals. The dorsal half of the neural spine is lost; the other half indicates that the spine was inclined backwards. Prezygapophyses are long and directed upwards, with articular facets looking upwards and inwards. The postzygapophyses splay outwards, and overhang the neural cavity. Their oval articular facets look outwards and downwards. The neural arch is remarkably low and also narrow, through the pedicles arising in the transverse median third of the dorsal surface of the centrum. The neural canal is small and subcircular. The diapophyses are long, and directed slightly upwards. They spring from the pedicles of the arch and the outer dorsal borders of the centrum. The centrum on an anterior view is wedge-shaped (fig. 5, XIV, p. 22), the narrow diameter being ventral. It is compressed from side to side. The lateral surfaces are flat in the median region, but with a pre-postaxial concavity due to a gradual expansion of the centrum to the articular borders. The articular

 $^{^1\,}$ L. Dollo, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) p. 245. $^2\,$ Id. ibid. p. 244.

surfaces are feebly concave. The ventral border is deeply notched, and its pre-postaxial extent very short, owing to the encroachment of the chevron-facets. Within the notch the surface is transversely convex. The articular surfaces for the chevrons are oblique one to the other. The anterior articular surface is less sharply outlined to the vertical axis of the centrum than the posterior. They are large and slightly concave, and much exposed on an anterior and posterior view. The chevron (fig. 5, XV, p. 22) is straight and moderately long. It is robust proximally, and perforated by a narrow slit-like foramen. It contracts in the median region; distally, it becomes laterally compressed and blade-like, but with little expansion. There are two articular

surfaces at the proximal end, a preaxial and a postaxial.

The chevron of the 4th caudal distally is style-like, and it is probable that the chevron of the 3rd caudal had a similar extremity. Unfortunately, the proximal end of that chevron is alone preserved. The larger of the two later caudals has the extremities of both the pre- and the postzygapophyses missing. They were doubtless long bar-like processes, with a moderate upward inclination and projection beyond the articular surfaces of the centrum. The neural arch is low. The articular surfaces are concave, with their borders raised above the lateral surfaces, giving a pre-postaxial concavity to the centrum. The latter is hexagonal with six flat surfaces, a dorsal surface forming the floor of the neural canal, two surfaces on each side divided by a longitudinal ridge, and a ventral surface. The length of the centrum equals the vertical diameter of the articular surfaces. Weak chevron-facets occur on the posterior ventral border.

The description of the larger terminal caudal applies equally well to the smaller, except that the hexagonal flat surfaces are more clearly defined by the raising of their separating borders, and the length of the centrum is now two-fifths greater than the

vertical diameter of the articular surfaces.

Ribs.

All the vertebræ from the atlas to the sacrum carry ribs. Prof. L. Dollo says that in *I. mantelli* and in *I. bernissartensis* the atlas and the last dorsolumbar carry no ribs. In the specimen here described the atlas, as proved by the facets on the postaxial ventral border of the intercentrum, possessed a pair of single-headed ribs, and what appears to be the left rib (fig. 5, II, p. 22) was found attached to the inner face of the left maxilla. It is single-headed, short, slightly curved, laterally compressed, bladelike, and Crocodilian in character.

Cervical ribs.—Nearly all the cervical ribs are lost and, with one exception, those that have been preserved have some portion

Op. cit. vol. iii (1884) p. 131.
 Ibid. vol. ii (1883) p. 245.

missing. The perfect rib is short, forked, curved dorso-ventrally, and ends distally as a style-like process. The capitular branch is a little more than twice the length of the tubercular, and is bent at an angle of 45° to the shaft of the rib, springing from its ventral border. The tubercular branch is produced from the dorsal border at the point of the divergence of the capitular branch. Both of these branches are moderately stout. The articular surface of the capitulum is convex, and that of the tuberculum concave. All the cervical ribs, with the exception of the first, are double-headed (fig. 10, V, p. 46).

Dorsal ribs.—Relatively to the size of the reptile the dorsal ribs (fig. 10, II, III, & IV, p. 46) are weak. The dorso-ventral curvature of the rib is greatest at the proximal end; distally there is little or no curve. In the earlier dorsal ribs the distal ends are style-like; but in the median dorsal ribs there is a gradual thickening distally, and their extremities are obtuse. The tubercular facet is situated at the termination of the dorsal border. At the proximal extremity of the rib, where it takes its greatest curvature, the pre- and postaxial surfaces are flat, and the rib shows a dorso-ventral expansion. The capitular branch is produced from the ventral border, and it is deeper than it is wide. The capitular facet is oval. The last dorsal (or sacrolumbar) rib is a single-headed, short, style-like bone.

The sacral ribs are described under the sacrum.

Appendicular Skeleton.

Scapula.—This bone (fig. 7, I, SC, p. 34) is long and slender, measuring about 570 mm, in length. The proximal end is broad and robust, the distal extremity an expanded thin plate. The length is a little less than four times the width of the distal end. In the median region it is relatively slender. The dorsal border of the scapula is almost straight. 'A strong protuberance with a well-defined triangular facet', as noted by C. W. Gilmore 1 in Camptosaurus, occurs on the preaxial border. From the outer angle of this triangle a very prominent ridge curves in a distal direction across the external surface, and fades away near the postaxial border of the narrowest part of the shaft. Between this ridge and the proximal border the exterior surface is concave, with a median pre-postaxial convexity. Below the articular surface for the coracoid, the scapula sends downwards a very strong outwardcurved process, cupped proximally, which forms the greater portion of the glenoid cavity (fig. 7, I, G, p. 34). The scapula is arched to take the curvature of the body-wall. The arching is greatest at the proximal end. The internal proximal border is deeply and widely notched at the lower third of the coracoid articular surface, so as to form a moiety of the interior lip of the coracoid foramen.

¹ Proc. U.S. Nat. Mus. vol. xxxvi (1909) p. 247.

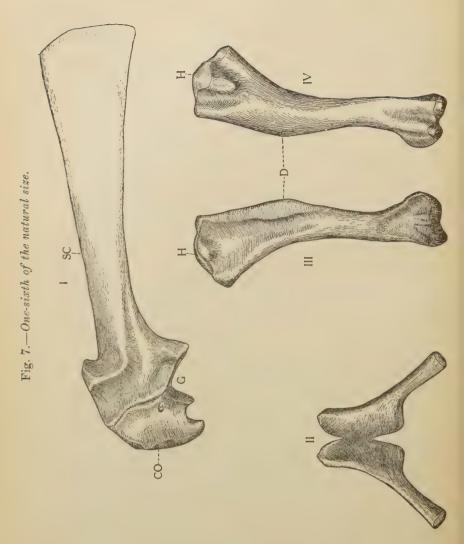
According to Gilmore, this notch is only found in the Dinosauria among the Camptosauridæ and Laosauridæ.

Coracoid.—The coracoid (fig. 7, I, CO, p. 34) is small, short, and broad, about 112 mm. long by 180 mm. in width. The proximal half is thick, and the distal half thin. The exterior surface is convex, and the interior deeply cupped, the result of a strong incurving of the distal border. The coracoid forms less than half of the glenoid cavity. The articular surface curves inwards and in an opposite direction to the glenoid articular surface of the scapula. The posterior border of the coracoid is short, and deeply hollowed. The distal border is rounded; but, near its posterior extremity, it flattens and thickens, forming an articular surface for the sternal plate. The foramen is complete, and is situated at 15 mm. from the glenoid cavity. The proximal border, which articulates with the scapula throughout its length, is notched on the interior surface at the same point as the proximal border of the scapula, the two forming together the interior exit of the coracoid foramen.

Sternal bones.—The sternal bones (fig. 7, II, p. 34), about 225 mm. in greatest length, were both lying in the matrix together, but with the inner border of the left bone slightly overlapping the inner border of the right. The left sternal bone was Iving in the matrix 65 mm. posterior to the left coracoid. Rather more than the anterior half of the bone consists of a gradually expanding plate, with the anterior portion of the inner border curved and the posterior straight: so that, when the two bones are articulated, there is an anterior V-shaped opening between them. The posterior border is hollowed. From the posterior external region of the sternal plate arises an outwardly-directed stout bar of bone, which continuously thickens dorso-ventrally, and terminates in a truncated end. This rod is nearly half the length of the bone, and is the 'xiphisternum' of Prof. Dollo. The outer border of the sternal plate is thick and concave. The greatest thickness of the bone occurs at the proximal end, which has a broad rugose surface looking forwards and inwards. The median area of the inner border is very sharp. The dorsal surface is slightly concave, and the ventral convex. On the anterior extremity of the sternal plate, looking outwards, is a flat, oval, articular facet for the coracoid.

The length of the fore-limbs is a little more than half the length of the hind-limbs.

Humerus.—This bone (fig. 7, III & IV, p. 34) is short, being 380 mm. in length; nevertheless it is the longest bone of the arm. It exhibits a sigmoidal flexure, the proximal end being



I. Exterior aspect of the left scapula and coracoid. SC, scapula; CO, coracoid; G, glenoid cavity; F, foramen. The coracoid, being in articulation and position as regards the actual skeleton, is foreshortened.

II. Sternal bones in articulation. Dorsal aspect.

III. Anterior aspect of the left humerus. H, head; D, deltoid crest.

IV. Posterior aspect of the left humerus. Same lettering.

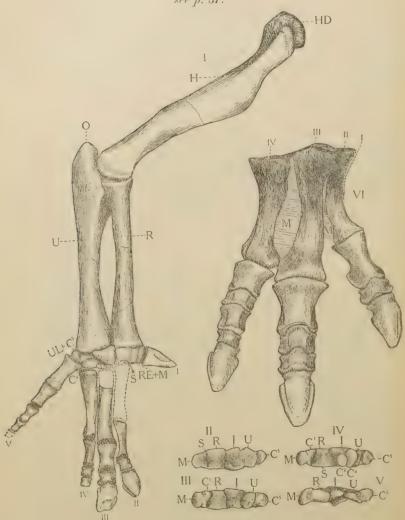
inclined slightly backwards and the distal end forwards. proximal end is widely expanded intero-exteriorly and compressed dorso-ventrally. The expansion gradually diminishes to the central region of the shaft, where a cross-section would be subcircular. There is a small medullary cavity. The proximal half of the bone is strongly curved inwards, so that the head lies interior to the plane of the distal half. The head is subspherical, is situated in the centre of the proximal end, and overhangs the dorsal surface of the bone (that is, its axis does not coincide with that of the shaft). The head is supported by a strong buttress of bone rising abruptly from the dorsal surface. The greater and lesser tuberosities are fairly well developed.

The ventral surface of the proximal half of the bone is concave, especially in the area bordered by the robust deltoid crest, which reaches its greatest development in the second quarter of the length of the preaxial border. The distal end of the humerus is moderately expanded and heavy. The radial and ulnar condyles are strongly defined, and separated dorsally by a deep wide valley, which receives the olecranon process of the ulna, when the arm is straightened. The ulnar condyle is produced farther distally than the radial condyle. The ventral surface of the distal end is concave; but, immediately above the trochlear surface, are two short ridges separated by a groove, that above the ulnar condyle being the more robust. There is a well-developed supinator ridge.

Radius.—The radius (fig. 8, I, R, p. 36) is about 270 mm. in length, and the shortest and smallest bone of the arm. The proximal end is expanded and semicircular; on the flat side is a triangular facet which articulates with the ulna. The shaft is much constricted. A cross-section would be elliptical, with the long axis pre-postaxial. The distal end is compressed dorsoventrally, and has a greater pre-postaxial expansion than the proximal extremity. The dorsal surface is gently convex, and the ventral slightly concave. Distally, the postaxial border is flattened, and articulates with a similar surface on the preaxial border of the ulna. The proximal articular surface is concave, and The radius articulates with the humerus in the distal convex. front of the ulna.

Ulna.—This bone (fig. 8, I, U, p. 36), about 340 mm. in length, is longer and much heavier than the radius, its proximal end being particularly massive, with a very robust olecranon process, which is produced proximally 45 mm. above the articular surface for the humerus. The articular surface is crescentic, its extremities being formed by strong and highly-developed wing-like expansions of the dorsal and ventral borders. The preaxial surface between these borders is deeply concave, with a flat median area. The radius articulates in this concavity. The ulna thus articulates with the humerus postaxially to, and in some degree both dorsally and ventrally to, the radius. The distal extremity of the ulna is

Fig. 8.—One-sixth of the natural size: for explanation, see p. 37.



much heavier than that of the radius. The distal articular surface is strongly convex. There is a moderate constriction in the median region of the shaft.

Carpus.—The carpus of each manus, when discovered, was in articulation with its radius and ulna. All the ossified elements of the left carpus are preserved, and were undisturbed. The carpus (fig. 8, IV, p. 36) consists of seven elements, three in the proximal row, the radiale, intermedium, and ulnare, and four in the distal row, carpalia 1, 3, 4, and 5. The proximal series (fig. 8, I–V) are not anchylosed, but are cemented together by a thin layer of matrix. Of the distal row, carpale 1 is almost entirely fused to the preaxial extremity of the radiale (fig. 8, III & IV, C¹), carpalia 3 and 4 are separate (fig. 8, IV, C³C¹), and carpale 5 is in part fused to the postaxial border of the ulnare (fig. 8, IV, C⁵). Carpale 2 was apparently an unossified element.

The radiale, as preserved, was evidently a composite bone, for near the central region of its proximal and distal surfaces it is pierced by a foramen (fig. 8, II, S, p. 36), from which, on both surfaces, a slightly curved groove extends to, and notches, the dorsal and ventral borders, but does not pass on to the dorsal and ventral surfaces. The bone, preaxially to the foramen and grooves, appears to comprise carpale 1 and the first metacarpal (fig. 8, II-V, M), and postaxially to the foramen, the radiale. On this identification the proximo-distal diameter of the fused 1st metacarpal and carpale 1 is greater than, its pre-postaxial diameter equal

EXPLANATION OF Fig. 8, p. 36.

I. Bones of the right fore-limb. The lateral aspect of the humerus is seen, and the dorsal aspect of the antebrachium, carpus, and manus. H, humerus; HD, head; R, radius; U, ulna; O, olecranon; RE+M, radiale plus 1st metacarpal; I, intermedium; UL+C⁵, ulnare plus carpale 5; S, area probably occupied in life by a cartilaginous carpale 2; C³, carpale 3; C⁴, carpale 4; I-V, digits.

radiate priss 1st metacarpai; I, intermedium; UL+C, ulhare priss carpale 5; S, area probably occupied in life by a cartilaginous carpale 2; C³, carpale 3; C⁴, carpale 4; I-V, digits.

II. Proximal aspect of the first row of the carpus. R, radiale; I, intermedium; U, ulnare; M, 1st metacarpal fused with the radiale; S, sulcus and foramen along the line of fusion; C⁵, carpale 5 fused

with the ulnare.

III. Distal aspect of the first row of the left carpus. R, radiale; I, intermedium; U, ulnare; M, 1st metacarpal fused with the radiale and carpale 1; C¹, carpale 1 fused with the 1st metacarpal and the radiale; C⁵, carpale 5 fused with the ulnare.

IV. Distal aspect of the left carpus. R, radiale; I, intermedium; U, ulnare; M, 1st metacarpal fused with the radiale and carpale 1; C¹, carpale 1; S, area occupied in life by a cartilaginous carpale 2; C³, carpale 3; C⁴, carpale 4; C⁵, carpale 5 fused with the ulnare.

V. Ventral aspect of the proximal row of the left carpus. R, radiale; I, intermedium; U, ulnare; M, 1st metacarpal fused with the radiale;

C5, carpale 5 fused with the ulnare.

VI. Right hind-foot. I, vestigial first metatarsal; II—IV, metatarsals and phalanges; M, matrix of iron pyrites. The second and ungual phalanges of the 4th toe have been restored from the same bones of the 4th toe of the left pes.

[Broken lines denote missing portions.]

to, and its dorso-ventral diameter less than, that of the radiale. Its dorsal and ventral surfaces have a longitudinal concavity. The preaxial border is expanded proximo-distally, and is elongateoval, with a convex articular surface for the spur-like pollex, the articular surface of which exactly fits and covers it. Carpale 1 appears to be wedged between, and fused to, the 1st metacarpal and radiale. The fusion of the 1st metacarpal and carpale 1 with the radiale is similar to that obtaining in Camptosaurus, and the position of carpale 1 is the same; but the 1st metacarpal is entirely fused to the preaxial, and not to the distal border as in Camptosaurus. Moreover, it is more vestigial, and takes a share in the articular surface for the radius, which articulates in a well-defined, elongated, and cupped surface formed by the 1st metacarpal and the radiale. Thus determined, the radiale is a block-like bone compressed in the median region proximo-distally and constricted pre-postaxially. Viewed proximally, it is of an hourglass-like form. The ventral half of its distal articular surface is flat, and is overarched by the dorsal half. The distal articular surface is bounded preaxially by carpale 1 and postaxially by the intermedium, which distally juts out considerably beyond the radiale, defining a quadrangular space. In a plaster-cast of the manus of I. bernissartensis in the British Museum, Natural History (R. 112), a similar feature is seen; but in that specimen the distal ventral border of the radiale is produced distally in addition, forming a quadrangular space into which the proximal end of the 2nd metacarpal fits, and is quite capped by the surrounding bones. It seems, however, that this space was occupied by carpale 1, which appears in life to have been represented by a plate of cartilage, as in Crocodilus, and, it is highly probable also, by a cartilaginous centrale between that and the radiale. The skeleton here described is that of a young individual, and the elements of the left carpus were undisturbed; yet no centrale or carpale 2 was found.

The intermedium dorsally is subtriangular, with the apex directed postaxially. Ventrally it has the same form, but its area is very much less, the result of a rapid compression of the bone on all borders, which begins at the dorsal third of the bone. Thus all the dorsal borders overhang the ventral border (fig. 8, V, I, p. 36). The preaxial border of the intermedium is wider than the postaxial border of the radiale, which articulates in the central region, so that dorsally the intermedium juts out beyond the radiale, both proximally and distally. The proximal surface is concave dorsoventrally, and forms nearly a half of the distal articular surface of the ulna. The distal surface articulates with three bones, a preaxial dorsal moiety with the third metacarpal, a central and ventral deep concave surface with carpale 3, and the postaxial surface with carpale 4. The postaxial border articulates with the

ulnare.

¹ C. W. Gilmore, 'Osteology of the Jurassic Reptile Camptosaurus, &c.' Proc. U.S. Nat. Mus. vol. xxxvi (1909) p. 253.

The ulnare is subcircular, viewed proximally: it is a plate-like bone. Preaxially, it articulates with the intermedium. Postaxially, it is fused to carpale 5; but a dorsal, ventral, and distal deep groove defines the line of union (fig. 8, II-V, C⁵). Proximally, the ulnare forms, with the intermedium and carpale 5, the ulnar articular surface. Distally, the ulnare articulates with carpale 4.

Carpale 1, as has been shown, is fused with the radiale and the

1st metacarpal.

Carpale 2 was probably cartilaginous.

Carpale 3 is a button-like bone (fig. 8, IV, C³). It is much smaller than carpale 4. Its proximal surface is conical, and the distal surface flat. Proximally, it articulates in the median region of the intermedium. Distally, it articulates with the 3rd metacarpal.

Carpale 4 (fig. 8, IV, C⁴) is a scale-like bone, with its dorsal border much thinner than the ventral. Both the proximal and the distal surfaces are slightly convex. Proximally, it articulates with

the intermedium and the ulnare.

Carpale 5 is fused to the postaxial border of the ulnare; but the line of union dorsally, distally, and ventrally, is at the base of a deep and wide valley. It stands out on these sides as a rounded boss-like bone. Proximally, it takes a share in the ulnar articulation, as it does, according to Marsh, in *Camptosaurus*, and distally it articulates with the 5th metacarpal.

Metacarpals.—Excepting the fused first metacarpals, there are only four preserved: the 3rd, 4th, and 5th of the right manus and the 5th of the left manus. The 3rd and 4th are relatively short (about 112 mm. and 110 mm. in length respectively) and their shafts subquadrangular in cross-section. The 3rd has lost its proximal end; but, from its well-defined articular space on the carpus, it must have been subquadrangular. The 3rd is stouter than the 4th, with a much greater distal expansion. Its distal articular surface is a well-defined trochlea. The proximal end of the 4th metacarpal is subquadrangular and stout; but, unlike the 3rd metacarpal, it gradually lessens in dimensions towards the distal end, and the preaxial border at its lower third becomes much The distal end is semicircular, the convexity being The articular surface is weakly convex, and looks postaxial. outwards, so that, when the third digit is in articulation, it is directed somewhat postaxially. The ventral surface of the bone is flat. The 5th metacarpal is a short stout bone, 55 mm. long, constricted in the median area, with well-expanded articular ends. The proximal articular surface is slightly concave, and the distal strongly convex. A cross-section of the shaft would be subcircular.

Phalanges of the manus.—Thirteen phalanges of the right manus and ten of the left have been discovered, so that, according to the phalangeal formula of *I. mantelli* and *I. bernissartensis*,

there are one phalanx of the right and four phalanges of the left manus missing. These are the terminal phalanx of the 5th digit of the right manus, the same phalanx and the three phalanges of

the 4th digit of the left manus.

As in *I. mantelli* and *I. bernissartensis*, the proximal phalanx of the 1st digit is absent, and the ungual phalanx is reduced to a conical spur; but the reduction is greater than in either of these two species, its length being less than a quarter of that of the longest tinger. Grooves for the reception of the horny sheath are present. The proximo-ventral borders of both right and left spurs show a strong outgrowth of bone directed proximally and free of the articular surface, which is due to a diseased condition of the bone. There is a well-formed articular surface, surrounded by a raised border. It is transversely concave, and articulates with the convex preaxial border of the fused 1st metacarpal. All except the terminal phalanges of the 2nd, 3rd, and 5th digits possess expanded, articular surfaces at both extremities, with a median constriction of their shafts.

The proximal phalanx of the 2nd digit is the longest of the phalanges, and is different in form from any other by reason of the proximal and distal expansions taking place entirely on the postaxial border. The proximal articular surface is slightly concave and the distal articular surface convex dorso-ventrally. The distal articular surface is oblique to the long axis of the bone, looking inwards and thus allowing the digit to splay preaxially and free the stout proximal joint of the median finger.

The proximal phalanx of the 3rd digit is short and robust. It is the stoutest phalanx of the digits. The dorsal and postaxial lateral surfaces are convex, and the preaxial, lateral, and ventral surfaces flat. The proximal articular surface is quadrangular, with two shallow concavities divided by a low ridge for the distal trochlea of the 3rd metacarpal. The distal articular surface is a particularly well-defined trochlea, which extends far on to both

dorsal and ventral surfaces.

The proximal phalanx of the 4th digit is much smaller, and slightly shorter than that of the 3rd digit. The proximal end is semicircular, and the articular surface is similar to that of the proximal phalanx of the 2nd digit. The distal articular surface is but slightly oblique, and looks postaxially, so that the end of this finger splays outwards.

The proximal phalanx of the 5th digit is of the same length as the same bone of the 4th digit, but is more robust. It differs from it in the dorsal and lateral surfaces being convex. The articular surfaces are both semicircular. The proximal articular

surface is concave, and the distal a simple convexity.

The second phalanges of the 2nd, 3rd, and 4th digits are block-like bones, with expanded extremities and median constriction. The dorsal and lateral surfaces are convex, and the ventral flat. Dorsally, the second phalanges of the 3rd and 4th digits are more laterally compressed than the 2nd phalanx of the 2nd digit. The

2nd phalanx of the 3rd digit is larger than the 2nd phalanges of the 2nd and 4th digits; and laterally, at the distal end, the bone is produced farther outwards than the preaxial lateral distal border, a feature which is not found in the corresponding phalanges of the

2nd and 3rd digits.

The proximal extremities of the 2nd phalanges of the 2nd, 3rd, and 4th digits are subcircular in outline. The articular surface of the 2nd phalanx is concave, and the 3rd and 4th possess surfaces to admit of articulation with the trochlear joints of the distal ends of the 1st phalanges of those digits. The distal articular surfaces are ill-defined trochlear surfaces.

The 2nd phalanx of the 5th digit is similar in form to the 1st phalanx of that digit, except that it is a shorter and smaller bone

with a greater median constriction.

The 2nd and 3rd digits are terminated by unguals. That of the 2nd digit is almond-shaped, and bears on its dorsal surface, near the inner lateral border, a deep sulcus, which passes on to the ventral surface near the proximal end. Near the outer border of the dorsal surface another and shallower groove occurs. At the proximal end the bone is constricted, forming a sort of neck. The dorsal and ventral surfaces are slightly convex. The preaxial border is nearly straight, and the postaxial curved. The bone is compressed dorso-ventrally. The articular end is subcircular, and the surface exhibits two shallow depressions divided by a low ridge.

The ungual of the 3rd digit is a depressed lozenge-shaped bone. Its dorsal and ventral surfaces are almost flat. Both lateral borders are curved. There are two grooves present on the dorsal

surface, and the bone is constricted near the proximal end.

The ungual of the right 3rd digit is deformed.

The 3rd phalanx of the 5th digit is a small bone constricted in the median region. The proximal end is much more expanded than the distal. The proximal articular surface is weakly concave, and the distal ball-like.

No 4th phalanx of the 5th digit was found, although in the left hand this digit was undisturbed and the phalanges were in position. By analogy with *I. mantelli* and *I. bernissartensis* there should be one; but the bone must have been extremely small, as is proved by the dimensions of the 4th phalanx and its restricted distal surface, which may be articular.

The 5th digit does not diverge so much from the other digits as is depicted in Prof. L. Dollo's figures of the manus of *I. mantelli*

and I. bernissartensis.

Ilium.—The preacetabular process of the ilium (fig. 10, I, IL, p. 46) is long, and nearly equal in length to half of the ilium. The process is shallow and directed downwards, with an expansion at the extremity, the inferior border of which is inclined outwards, a characteristic seen in other Iguanodonts, such as *I. dawsoni* and *I. fittoni*. This inclination is necessary to free the dorsolumbar ribs, over which the preacetabular projection closely hangs. A

strongly-developed roof-like shelf is present on the interior surface, arising at the point where the extension leaves the body of the ilium. It fades away just before the anterior expansion is reached. When in position, the preacetabular process extends to the 15th dorsolumbar, or the 26th vertebra in consecutive series. The superior border of the ilium is strongly convex pre-postaxially, the centre of the arch being situated above the acetabular notch. There is a feeble reflection of the superior border, which is confined to the area between the pre- and postacetabular notches. The body of the bone is remarkably thin. The postacetabular extremity is the thickest portion. The exterior surface is weakly concave, under the reflected area of the superior border. In the same region, the upper interior surface is inclined inwards and downwards to about half the depth of the ilium, below which it is vertical. The articular facets for the transverse processes of the sacral vertebræ are shallow and ill-defined, except that of the first, which receives the transverse process of the first sacral vertebra. That facet occurs at the base of the inner shelf of the preacetabular process. Between the superior and acetabular borders the ilium is moderately deep. The depth from the dorsal border to the lower angle of the pubic process exactly equals the length of the postacetabular process.

The postacetabular extension is a shallow plate, and terminates in an obtuse point with an intero-exterior expansion. This expansion produces a longitudinal swelling on both lateral surfaces. There is no inferior inner shelf-like projection, as seen in I. fittoni. The postacetabular extension from the ischial tuberosity is a little less than a third of the length of the ilium. The preacetabular notch is wide. The pubic peduncle is long and deflected. The lower angle of the extremity alone articulates with the pubis, the distal surface looking forwards, not downwards as in I. mantelli and I. bernissartensis (as seen in Prof. Dollo's figures), and a cartilaginous pad must have filled the gap. The inner border is greatly expanded, very strong, and arched, with a slightly concave inferior surface which roofs the head of the femur. The acetabular border is well defined. The ischial peduncle is quite flat on the inner lateral surface. In I. mantelli there is a highly-developed shelf, directed inwards from this surface. The outer surface of the ischial peduncle at the base of the postacetabular process suddenly swells, and becomes a robust tuberosity. It is long pre-postaxially, and has a straight

inferior border with a rugose articular surface.

On a ventral view the contour of the ilium closely resembles that of *I. mantelli*, as figured by R. Lydekker.² Its maximum length is 670 mm., and the greatest width of the acetabulum is 130 mm.

Pubis.—The preacetabular projection of the pubis (fig. 10, I, P,

Q. J. G. S. vol. xlvi (1890) p. 38.

² *Ibid.* fig. 1, p. 37.

p. 46) is a short, thin blade of bone moderately expanded at the distal extremity on the dorsal border only. Its greatest length from the centre of the acetabular border is 320 mm., and its greatest depth at the distal end is 135 mm. The dorsal border is deeply excavated, and is thicker than the inferior border, which is quite sharp, and (except for a slight swelling in the hinder third of its length) is nearly straight. Viewed dorsally, the bone is slightly sigmoidal. Proximally, the pubis is considerably thickened, more especially superiorly. On the dorsal border is a triangular surface, which articulates with the pubic peduncle of the The acetabular border is a concave, broad, articular surface. Inferiorly this surface gradually contracts, and terminates in a short stout process, produced from the proximal inferior border. This process bounds supero-posteriorly a large pubic foramen which is bordered anteriorly by the post-pubis. The latter sends up a tongue of bone to border inferiorly, but not completely to close, the pubic foramen. That is accomplished by the anterior border of the wing-like plate sent forward from the proximal anterior border of the shaft of the ischium. The distal extension of the post-pubic bone is missing.

Ischium.—The ischia suffered much in their fall from the cliff, and the greater portions of their shafts are lost. The parts preserved are the iliac and pubic branches of the left ischium, the iliac branch and a large portion of the obturator process of the right ischium, moieties of both the shafts near the distal ends, and their distal extremities. The ischium will be described from this material.

The proximal end of the ischium (fig. 10, I, IS), which measures 245 mm. in length, is widely branched, with a broad, deep excavation of the proximal border, forming a portion of the inferior and posterior boundary of the acetabulum. The iliac branch is much heavier than the pubic branch. The proximal articular surface is expanded transversely and concave anteroposteriorly, and it articulates with the whole ventral surface of the post-acetabular peduncle of the ilium. The pubic branch is a wing-like plate of bone with an antero-inward curve. A transversely widened surface at its anterior extremity articulates with the post-pubic process. The obturator process is a moderatelydeveloped thin plate of bone, situated on the inferior border, a short distance distally to the pubic branch of the ischium. The shaft of the ischium begins with a triangular cross-section, which gradually changes distally to a subcircular section, and then again becomes triangular, with the apex of the triangle forming the anterior border. The distal extremity is much expanded anteroposteriorly, with almost flat intero-exterior surfaces. Judging from the position in which they are preserved, the distal ends of the ischia and some considerable portion of their shafts were in contact, as in I. mantelli and I. bernissartensis and also in Camptosaurus, but were not joined by symphysis.

Fig. 9.—One-sixth of the nutural size: for explanation, see p. 45. Ξ

Femur.—This (fig. 9, I, p. 44) is the longest and stoutest bone in the skeleton: it is 678 mm. long. The shaft is curved, and the clearly-defined, robust, and subspherical head is placed at right angles to it. The dorsal surface of the head is rugose. The neck is compressed antero-posteriorly. The greater trochanter is very massive, with a wide pre-postaxial expansion, and is produced proximally above the plane of the head. The surface between the head and the great trochanter is deeply concave. The smaller trochanter originates from the preaxial exterior border of the shaft, is produced upwards, and terminates before the proximal border of the femur is reached. It is separated from the great trochanter by a long, narrow, oblique cleft. A weak ridge is continued from the base of the smaller trochanter, curving across the anterior face of the shaft, and ultimately becoming absorbed into the inner convex border, immediately above the inner condyle. This ridge divides two flat surfaces, set obliquely one to the other. The postaxial surface of the shaft is feebly convex. In the longitudinal median region of the shaft, on the posterior edge of the inner border, is abruptly developed a strong crested trochanter (fig. 9, I, IT, p. 44) intero-posteriorly directed. Its interior surface is concave. Distally, the shaft terminates in two well-defined condyles, an inner and an outer (fig. 9, I, IC & OC), separated anteriorly and posteriorly by deep intercondylar grooves, which are not opposite one to the other. That on the preaxial surface is near the outer border of the exterior condyle, and that on the postaxial surface is near the inner border of the interior condyle. The inner condyle is much more robust than the outer, and its articular surface is of greater extent—not only from its greater antero-posterior expansion, but by its continuation on to the postaxial surface of the condyle. The interior distal border of the inner condyle shows numerous oblique striæ. The inner border of the outer condyle is posteriorly produced into a stout ridge, between which and the external border is a longitudinal concavity. The femur possesses a medullary cavity.

Tibia.—This bone (fig. 9, II & III, p. 44) is robust, and shorter than the femur, measuring only 595 mm. in length. The proximal extremity is heavier than the distal. It is expanded

EXPLANATION OF FIG. 9, p. 44.

I. Interior aspect of the right femur. H, head; LT, lesser trochanter; IT, inner trochanter; IC, inner condyle; OC, outer condyle.

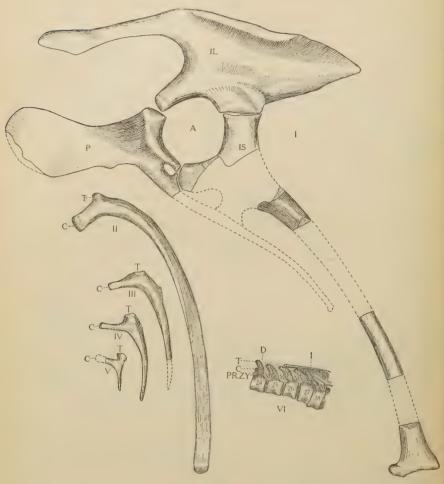
IV. Proximal aspect of the left distal row of tarsals. OT, outer tarsal;
IT, inner tarsal.

[Broken lines denote missing portions.]

<sup>II. Preaxial aspect of the right fibula and tibia. F, fibula; U, tibia;
CN, cnemial crest; IC, inner condyle; CA, calcaneum; A, astragalus.
III. Postaxial aspect of the right fibula and tibia. F, fibula; V, tibia;
CA, calcaneum; A, astragalus.</sup>

V. Preaxial aspect of the left distal row of tarsals. OT, outer tarsal; IT, inner tarsal.

Fig. 10.—One-eighth of the natural size, with the exception of VI, which is one-sixteenth of the natural size.



I. Left pelvic girdle. IL, ilium; P, pubis; IS, ischium; A, acetabulum.

II. A left median dorsal rib. C, capitulum; T, tuberculum.

III. An early dorsal rib. Same lettering.

IV. A very early dorsal rib. Same lettering.

V. A cervical rib. Same lettering.

Broken lines denote missing portions.

VI. Ventro-lateral aspect of the five last dorsolumbar vertebræ, showing the preaxial curvature of the diapophyses and the ribs. The diapophyses of the 25th, 26th, and 27th vertebræ bear the proximal ends of the ribs. The single-headed rib of the 28th vertebra has been pressed behind its diapophysis, and the 28th vertebra is displaced below its true position. I, pre-acetabular process of the left ilium; D, diapophysis; T, tubercular facet; C, capitular facet; PRZY, prezygapophysis. The pre- and post-zygapophyses (where not exhibited) are hidden by the matrix.

both intero-exteriorly and pre-postaxially, the latter expansion being the greater. This expansion occurs on the inner portion of the bone, and supports a robust condyle, which is separated by a deep intercondylar groove from a strongly defined condyle on the outer side of the tibia. The articular surfaces of these condyles are of great pre-postaxial extent, convex in that direction, and produced so far on to the posterior surface that their terminations

are postaxial.

The preaxial, outer, proximal border of the tibia is produced into a powerful enemial crest (fig. 9, II, CN, p. 44) directed outwards. On this border, posterior to the crest, there is a flat surface which receives the inner surface of the proximal end of the fibula. When articulated, this extremity of the fibula is nearly hidden, on a direct anterior view, by the crest. From the distal border of the crest a ridge passes across and down the preaxial surface of the shaft, fading away in the longitudinal median region, near the inner border. The outer margin of the bone is angular, through the convergence of the preaxial and postaxial surfaces, which are oblique one to the other. In the middle the shaft begins to expand in an intero-exterior direction. This expansion continues to the distal end, where it is much greater than the pre-postaxial expansion. Thus the axis of greatest expansion is nearly at right angles to that of the proximal end. The postaxial distal surface of the bone is concave.

The shaft of the tibia is curved, especially the lower half, the convexity being postaxial. The distal articular surface looks forwards and outwards.

Fibula.—This bone (fig. 9, II & III, F, p. 44) is long and slender, but shorter than the tibia, being only 564 mm. in length, The proximal end is expanded pre-postaxially, with a broadly-convex outer surface, and a flat inner surface which articulates with the tibia. The proximal articular surface is weakly convex transversely. The pre-postaxial diameter continues greater than the transverse, until the median region of the shaft, where the intero-exterior diameter becomes the greater. The preaxial surface is angulated throughout its length. The distal extremity is fairly robust. Preaxially, it is produced into a rounded process; but postaxially the surface is flat, and articulates with the tibia. Proximally, the fibula is free of the tibia, except at the extremity; but its distal half is closely applied to that bone. The distal articular surface for the calcaneum is convex.

Tarsus.—Four bones are comprised in the tarsus, two in the

proximal and two in the distal row.

The astragalus (fig. 9, II & III, A, p. 44) is the biggest bone of the tarsus. It is apparently fused with the calcaneum, but not with the tibia, for there is a layer of pyrites between them. The proximo-distal diameter is much greater at the outer border than at the inner. The proximal articular surface is

concave, and the distal strongly convex. There is a weakly-developed ascending process on the anterior proximal border. The astragalus, when in articulation, is much more exposed in

front than behind.

The calcaneum (fig. 9, II & III, CA) is not fused with the fibula. The extero-interior diameter is much shorter than that of the astragalus, and its preaxial border much deeper than the post-axial. When viewed from behind, it is even less exposed than the astragalus. The preaxial proximal surface is weakly concave antero-posteriorly, for the reception of the fibula. The proximal postaxial surface is occupied by the tibia, which not only overlaps

the fibula intero-exteriorly but also distally.

The distal tarsals (fig. 9, IV & V, p. 44) are not fused with the metatarsals. With the exception of the inner tarsal of the right pes, which is perfect, all the others are fractured, and portions of them are missing. The outer tarsal (fig. 9, IV & V, OT) is a block-like bone, and, if we may judge from the size of the area of the proximal surface of the 4th metatarsal, only a small portion of its border has been broken off, the perfect bone being quadrangular. The proximal surface is weakly concave, and the distal feebly convex. The outer border of the bone is deeper than the inner border. It articulates proximally with the calcaneum, and distally with the 4th metatarsal. The inner tarsal (fig. 9, IV & V, IT) is an ovate bone, with rounded borders. Its proximal articular surface is slightly cupped; while the distal articular surface is strongly convex on its outer half, and deeply concave on its inner half. The bone is not nearly so deep as the outer tarsal. It articulates proximally with the astragalus, and distally with the 3rd metatarsal.

Metatarsals.—The 2nd, 3rd, and 4th metatarsals of both pedes have been preserved (fig. 8, VI, p. 36). No rudimentary 1st metatarsal was found; but doubtless it was represented in life, as in *I. mantelli* and *I. bernissartensis*. The 5th metatarsal is wanting. The 2nd metatarsal is the shortest of the three, measuring 173 mm. in length, and its proximal end is much expanded antero-posteriorly and compressed intero-exteriorly. The proximal articular surface is nearly flat. In the median region the shaft is constricted, but the antero-posterior diameter is still much the greater. The exterior edge of the anterior border is produced into a lip, which overlaps the inner anterior border of the 3rd metatarsal. From the proximal end to this lip the 2nd metatarsal is closely applied to the 3rd; but, distally to it, the bone is bent inwards, so that the widely-expanded, convex, distal articular surface is oblique to the plane of the proximal articular surface, and looks downwards and inwards. The distal inner surface of the bone is deeply depressed for ligamentary attachment. The 3rd metatarsal is the heaviest and longest of the three, being 240 mm. in length. The proximal end is quadrilateral, with the inner side longer than the others. Its articular

surface is strongly convex on the anterior two-thirds, and is produced above the plane of the articular surfaces of the 2nd and the 3rd metatarsals. The median region of the shaft is slightly constricted. The distal end is robust and expanded, with deep depressions on the inner and outer surfaces. The articular surface is a trochlea. As noted by Prof. Dollo, in the Iguanodon of Bernissart this metatarsal juts out over its neighbour, not only in its length, but also pre-postaxially. The 4th metatarsal is intermediate in size between the 2nd and the 3rd, being 185 mm. Its proximal end and the shaft are expanded interoexteriorly; that is, in a reverse manner to those of the 2nd metatarsal. The proximal articular surface is weakly concave, and is smaller in area than that of either of the other metatarsals. Below the articular surface the inner border expands in an interior direction for about half its length, and is closely applied to the outer border of the 3rd metatarsal. The distal half of the bone is constricted, and is free of the 3rd metatarsal, until the extremity is reached, where the bone again becomes expanded and is closely applied to the 3rd metatarsal by its inner border. The posterior margin of the exterior surface is produced farther outwards than the anterior margin, and the area between them is deeply depressed. The articular surface is strongly convex, and looks outwards and downwards.

Phalanges of the pes.—Except the 2nd and ungual phalanges of the 4th toe, all the phalanges of the right pes (fig. 8, VI, p. 36) have been preserved, as also the proximal phalanges of the left pes; all the others of that foot are missing. The phalaugeal formula is 0, 3, 4, 5, 0, and is therefore similar to that of I. mantelli and I. bernissartensis. The proximal phalanx of the 2nd toe (99 mm. in length) is the longest and most slender, that of the 4th toe (70 mm. in length) the shortest, and that of the 3rd (85 mm. in length) the stoutest. The proximal articular surface of the proximal phalanx of the 2nd toe is subtriangular and concave. The outer border of the bone is convex, and the inner border flat; but, owing to the expansion of the ends of the bone, there is a longitudinal concavity, a feature which characterizes all the phalanges of the three toes, with the exception of the ungual phalanges. The distal articular surface is a well-defined trochlea. There are two deep and wide depressions for ligamentary attachment on the lateral surfaces. The 2nd phalanx is very short. The proximal dorsal and ventral borders are produced proximally into lips, and the lateral borders are hollowed. The proximal articular surface is convexo-concave for the reception of the trochlear joint of the proximal phalanx, and the distal articular surface is a trochlea. The dorsal surface of the bone is convex, the sides depressed, and the ventral surface flat. The ventral surface is much wider than the dorsal, a characteristic

¹ Bull, Mus. Roy. Hist, Nat. Belg. vol. ii (1883) p. 105. Q. J. G. S. No. 321.

found in all the median phalanges. The ungual phalanx is long, depressed dorso-ventrally, and outcurved. The proximal articular surface is the same as that of the 2nd phalanx, but is not so strongly developed. Distally to, but near, the articular surface, the bone is constricted, then rapidly expands, producing a ledge on each of the lateral borders. A deep longitudinal groove occurs on the dorsal surface of the inner ledge. The ledge and the groove form together the support for the claw. The proximal phalanx of the 3rd digit is quadrangular; the dorsal and ventral surfaces are wider than the lateral. The proximal end is more expanded than the distal, and its articular surface is concave, with a weak median convexity. The distal articular surface is a trochlea. The 2nd and 3rd phalanges are stouter than, but are similar in form to, the 2nd phalanx of the 2nd digit. The ungual phalanx differs from that of the 2nd toe in that it is stouter, straight, and has a groove on the dorsal surface of each lateral border. The proximal phalanx of the 4th digit is a short and very robust bone. It is much stouter than that of the proximal phalanx of the 3rd digit; otherwise its features are similar. The 2nd phalanx possesses the same characteristics as those seen in the 2nd phalanx of the 2nd digit and in the 3rd and 4th of the 3rd digit, except that the lateral surfaces are more depressed. The 3rd phalanx is longer than the other phalanges of the pes, except the proximal and ungual phalanges. The lateral surfaces are even more depressed than those of the 2nd phalanx. The 4th phalanx is a much smaller and shorter bone than the 3rd phalanx, and the lateral depressions are not so great. It is the smallest bone of the toes. The ungual is similar to that of the 2nd digit.

Integument.

A portion of the skin has been described and figured 1; but, as the clearing of the bones from the matrix proceeded, several other fragments have been discovered, which exhibit the same extreme thinness of the integument and its covering of small convex tubercles. The tuberculate condition of the integument was continued even to the inside of the fingers, for a portion of the skinimpression is still attached by matrix to the inner surface of the 1st phalanx of the 5th digit of the right manus. In addition, during the removal of the matrix overlying the exterior surface of the proximal end of the right ulna, a portion of a similar skinimpression was discovered, which was connected with a cluster of seven large feebly-convex tubercles (Pl. II, fig. 5). Two more large tubercles were found on a smaller piece of matrix, and a single large tubercle on another. These plates are polygonal, with their outer surfaces slightly rugose. The largest plate is 22 mm. long and 19 mm. wide, and the smallest 15 mm. long and 18 mm. wide. It was remarked (op. cit. p. 149): 'It appears therefore

¹ R. W. Hooley, Geol. Mag. 1917, pp. 148-50 & pl. x.

probable that on those parts of the body exposed to the sun large, flat tubercles would be found, as in *Trachodon annectens*.' This is now proved to be the case, and further that not only the 'ground-plan' of the epidermis of *Iguanodon* is essentially similar; but also that the integument was ornamented with groups of large plates, as in *Trachodon*.

III. COMPARISONS WITH OTHER SPECIES.

Skull.

On comparing the skull of I. atherfieldensis with that of the type-skull of I. bernissartensis, it is evident that, in the latter, the upper and lower arches of the left side have been distorted and several of the bones displaced.\(^1\) Thus the jugal is lying interior to the maxilla and not in articulation with it, but driven forwards into the nasal capsule, and its hinder end depressed. The jugopostfrontal process is pushed into the orbit, mis-shaping the latter. The quadrate process of the jugal, determined by Prof. L. Dollo to be a portion of the quadratojugal, is broken and crushed into the infratemporal fossa. The jugal is triradiate and not crescentic.2 The quadratojugal (r) in Dollo's figure is the posterior end of the jugal, and is lying partly behind the quadrate process of the jugal in the 'foramen quadratique' of Dollo, and, if in position, would occupy the whole of that space. The quadrate has been dislocated from its distal articulation, the result being that the real outlines of the orbits and the supra- and infra-temporal fossæ are not exhibited. The crumpling of the lower arch also explains the apparently remarkable feature in the type-skull, that the dental series is continued behind the orbit, towards the middle of the temporal fossa 3; for doubtless the dental series, in an undistorted skull, would cease below the posterior end of the orbit, and the coronoid process would be under the orbit and not beneath the infratemporal fossa, thus agreeing not only with the skull here described, but also with that of *I. mantelli*. In Dollo's ⁴ figure of the latter skull it is also clear that distortion by pressure has taken place, for the quadrate and the postfrontal are disjointed, so that the real forms of the supra- and infratemporal fossæ are not seen.

The lower jaw of *I. bernissartensis* ⁵ has obviously suffered in the same manner, and this alone can explain the fact that the angular and surangular are, according to Dollo, only visible on the interior face. Gilmore's suggestion that the presence of the foramen proves that the bone denoted Z¹ in Dollo's figure is in reality the surangular, is doubtless correct. The weak posterior extremity

¹ L. Dollo, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) pl. ix, fig. 1.

² K. A. von Zittel, 'Text-Book of Palæontology' Engl. transl. [C. R. Eastman] vol. ii (1902) p. 238.

³ L. Dollo, op. cit. p. 226.

⁴ *Id. ibid.* vol. iii (1884) pl. vi, fig. 3.

of the lower jaw seems anomalous. The angular was evidently exposed on the exterior face, as in *Iquanodon atherfieldensis*.

The premaxillary superior apophyses in the figures of the skull of *I. bernissartensis* appear to underlie the nasals, which is contrary to analogy. They overlie them in *I. atherfieldensis* and apparently in *I. mantelli*. It may be that in *I. bernissartensis* they just meet the nasals, as in *Camptosaurus*.

The length of the skull in *I. mantelli* is three times its width, in *I. atherfieldensis* two and a half times, and in *I. bernissartensis*

double. The bony ridge on the anterior dorsal border of the premaxillæ is not seen in I. mantelli or in I. bernissartensis. high elevation of the nasals above the dorsal outline of the skull in I. mantelli is absent in I. bernissartensis and I. atherfieldensis. The extension of the lower premaxillary apophysis to the lachrymal, the exclusion of the nasal and prefrontal from the maxilla, the elevation of the dorso-posterior border of the squamosal into a crest, and the great ventral production of the posterior border of that bone in I. atherfieldensis are features not found in the skulls of I. mantelli or I. bernissartensis. In Trachodon and Telmatosaurus the premaxillary apophyses extend to the lachrymals, and Baron F. Nopesa 1 says that this feature is of great importance as a distinguishing mark from the Iguanodonts; but we now know that this character is found in I. atherfieldensis, and it seems almost certain that well-preserved skulls of young individuals of I. mantelli and I. bernissartensis would reveal a similar relationship. The head of the quadrate is more deeply overlapped by the squamosal in I. atherfieldensis than in I. mantelli or in I. bernissartensis and, moreover, articulated with that bone, whereas in the other two species it is said to be fixed. The quadrate is more curved than in I. bernissartensis. but similar to that seen in I. mantelli. The nares are more elongated than in I. bernissartensis, but much less so than in I. mantelli, and different in form from either. The large subcircular orbit is near in form to the orbit of I. mantelli and Camptosaurus, and differs considerably from that of I. bernissartensis, unless the post-mortem compression already referred to has disturbed the elements forming its boundary. The infratemporal fossæ are much greater in dimensions than, and different in outline from, those of I. mantelli, and relatively of greater size than in I. bernissartensis. There are two fewer functional teeth in the upper jaw, and one more in the lower jaw, than in I. bernissartensis. The number of teeth in the jaws of I. mantelli has not been stated.

The teeth of the Bernissart specimens of *I. mantelli* and *I. bernissartensis* have not been described, and those in the figured mandible of *I. bernissartensis* ² lack too much in detail for comparison. Prof. Dollo says that he left for his definitive work a

¹ Denkschr. K. Akad. Wissensch. Wien, vol. lxviii (1900) p. 570.

² L. Dollo, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) pl. ix, fig. 3.

detailed description of the dentition, already sufficiently known through the researches of British palæontologists. The consequence is, that it is not possible to compare the teeth of I. atherfieldensis with the described teeth, for the latter reveal many marked specific differences, and yet they have nearly all been assigned to I. mantelli by Mantell, Owen, Hulke, and others. Sir Richard Owen 1 says that

'In most of the teeth that have hitherto been found, three longitudinal ridges traverse the outer surface of the crown, one on each side of the median primitive ridge; these are separated from each other and from the serrated margins of the crown by four wide and smooth longitudinal grooves. The relative width of these grooves varies in different teeth; sometimes a fourth small longitudinal ridge is developed on the outer side of the crown.'

G. A. Mantell 2 notes 'the presence of from two to three or four longitudinal ridges down the enamelled face.' In some figured specimens, moreover, many of the marginal lamine are continued on to the surface of the tooth as prominent ridges, reminding one of those seen in Camptosaurus. In this respect, compare the right mandibular ramus figured by Owen 3 as belonging to I. mantelli, and also the left mandibular ramus of a 'young Iguanodon' which, from the number of alveoli and the conspicuous tertiary ridges, certainly belongs to Camptosaurus. This ramus has been queried by Sir Arthur Smith Woodward & C. D. Sherborn 5 as belonging to that genus. H. A. Nicholson & R. Lydekker 6 figure a lower tooth of I. bernissartensis from the Wealden of Sussex. If this tooth really belongs to that species, then the specimen here described differs from it in possessing a tooth with a crown longer, narrower, and with the primary and secondary ridges parallel and almost equally developed. Sir Arthur Smith Woodward ingures four unworn teeth of I. mantelli (after Owen). Although they approximate in form to the teeth of I. atherfieldensis, the primary ridge appears to be much more highly developed than the secondary ridge, and tertiary ridges are present, which do not occur on the teeth of the skull under review. In that skull the similarity of the ornamentation of the teeth is remarkable, yet, in the described material, teeth with marked differences in sculpturing have been assigned to either I. mantelli or I. bernissartensis, whereas they doubtless belong to several species.

The mandibular teeth of I. hoggii 8 differ from those of I. atherfieldensis in having two unequally developed parallel ridges, in

'Petrifactions & their Teachings' 1851, pp. 235-36.

Catal. Brit. Foss. Vert.' 1890, p. 213.
 Manual of Palæontology' vol. ii (1889) fig. 1055.

^{1 &#}x27;Fossil Reptilia of the Cretaceous Formations' Monogr. Palæont. Soc. 1851, pt. i, p. 115.

^{3 &#}x27;Reptilia of the Wealden & Purbeck Formations' Monogr. Palæont. Soc. Suppl. v (1874) pl. i, fig. 1.

Ibid. Suppl. iii (1864) pl. x, fig. 1.

Outlines of Vertebrate Palæontology '1898, p. 207, fig. 127.
 R. Owen, 'Reptilia of the Wealden & Purbeck Formations' Suppl. v. Monogr. Palæont. Soc. (1874) p. 4.

possessing more strongly-defined flutings between and on each side of the ridges, and in having marginal serrations with smooth edges.

The parallelism of the dorsal and ventral borders of the region carrying the teeth in the lower jaw noted by Prof. L. Dollo in *Iquanodon bernissartensis* is not found in *I. atherfieldensis*. The ventral borders behind the coronoid processes are directed downwards to a much greater degree in the latter than in the former, or than in *I. mantelli*. In *Camptosaurus* the ventral border is almost straight.

The skull of *I. atherfieldensis* is intermediate in form between that of *I. mantelli* and *I. bernissartensis*. In the other described species the skull is not known.

Vertebral Column.

Prof. Dollo has not figured, other than in the restored skeletons, or described in detail, the vertebræ of either *I. mantelli* or *I. bernissartensis*. However, of the former, we have for comparison the dorsal and caudal vertebræ of the type-specimen ¹ from the Kentish Rag of Maidstone. These with the other odd vertebræ, which have been referred to that species by different authorities, as well as those which have been assigned to *I. bernissartensis*, we must use as material.

No cervical vertebra is present on the slab containing the typespecimen of *I. mantelli*, and the crushed cervical vertebræ, figured by Sir Richard Owen² as types of *Streptospondylus major*, and assigned by R. Lydekker³ to *I. bernissartensis*, are too imperfect for profitable comparison. In the cervicals of *Camptosaurus* prestwichii the centrum is more triangular, and the anterior ball is not so highly developed as in *I. atherfieldensis*.

Comparing the median dorsal vertebræ of the type-specimen of *I. mantelli* and the dorsals referred to *I. bernissartensis* by Owen ⁴ and Lydekker ⁵ respectively, we observe that the neural arch is much higher in these two species than in *I. atherfieldensis*, and the anterior contours of the centra of all three differ one from the other, the last-named being intermediate between the two former. In *I. mantelli* the anterior contour is subcircular, and the transverse diameter is slightly greater than the vertical, with no lateral compression near the ventral border; while in *I. bernissartensis* the vertical diameter is much greater than the transverse, and the lateral borders are nearly vertical, with the ventral third strongly compressed laterally. In *I. atherfieldensis* the vertical and transverse diameters are equal in the early dorsals (fig. 5, XI,

¹ G. A. Mantell, 'The Wonders of Geology' 1st ed. (1838) pl. iii; R. Owen, 'Fossil Reptilia of the Cretaceous Formations' Monogr. Palæont. Soc. pt. 1 (1851) pls. xxxiii, xxxiv.

² Reptilia of the Wealden & Purbeck Formations Monogr. Palæont, Soc. Suppl. 2 (1859) pl. vi, fig. 1.

³ Brit. Mus. Catalogue of Fossil Reptilia & Amphibia, pt. i (1888) p. 204. ⁴ 'Fossil Reptilia of the Cretaceous Formations' Monogr. Palæont. Soc. pt. 1 (1851) pls. xxxiii–xxxiv.

⁵ Brit. Mus. Catal. of Fossil Reptilia & Amphibia, pt. i (1888) p. 205, fig. 42.

p. 22), and in the tenth dorsal (fig. 5, XII, p. 22) the vertical diameter is greater than the transverse; the lateral borders are convex, with their ventral moieties weakly compressed, forming a truncated oval outline. In I. dawsoni a middle dorsal vertebra has the transverse diameter greater than the vertical, a character which separates it from all three of the above-mentioned species. In a middle dorsal vertebra referred by Lydekker 2 to I. hollingtoniensis, the vertical diameter is slightly greater than the transverse. The preaxial reflection of the diapophyses of the last five dorsal vertebræ in I. atherfieldensis is a unique feature, no

vertebrate known to me having a similar adaptation.

The sacrum of *I. atherfieldensis*, comprising six fused vertebra, agrees with that of I. bernissartensis, and differs from that of I. mantelli, which has only five. In no other respect can a comparison be made, on account of the absence of description and figures of the Bernissart specimens, and in the type-block of I. mantelli the sacrum is missing. There is a sacrum in the British Museum (specimen No. 37,685), which has been described by Owen,3 figured by Mantell 4 and Owen,5 noticed by J. W. Hulke 6 and catalogued by Lydekker 7 under I. mantelli. Hulke doubts the reference of this specimen to I. mantelli. This certainly differs from the specimen now under review, not only in having one less fused vertebra, but also considerably in the ventral surfaces of the first three sacral vertebræ, which are compressed and carinated. In I. atherfieldensis there is an almost entire absence of keel, and the vertebrae have not the same uniformity in size and contour. Again, the cylindroid and grooved third and fourth centra are quite different, as are the greater width and the flat hæmal surface of the fifth centrum.

The sacrum of I. dawsoni is unknown.8 The sacrum of I. fittoni is not thoroughly known. There is an imperfect sacrum (Brit. Mus. specimen No. R 1635 b) referred to this species by Lydekker 9 the vertebre of which, he says, 'although larger, are in the same form as in the sacrum referred to I. mantelli (Brit. Mus. No. 37.685).' It has already been shown that there is a doubt as to the correctness of the reference, and in any case the sacrum

differs considerably from that of I. atherfieldensis.

The sacral vertebra of I. hollingtoniensis are not fused, and have flat hæmal surfaces, 10 thus differing in both particulars from

Id. ibid. pt. iv (1890) p. 264.

³ Rep. Brit. Assoc. (Plymouth) 1841, p. 131.

⁶ Q. J. G. S. vol. xxxvi (1880) p. 447.

¹ R. Lydekker, Brit. Mus. Catalogue of Fossil Reptilia & Amphibia pt. i (1888) p. 197.

Phil. Trans. Roy. Soc. vol. exxxix (1849) pl. xxvi.
 'Reptilia of the Wealden & Purbeck Formations' Monogr. Palæont. Soc pt. 2 (1855) pls. iii & iv.

⁷ Brit. Mus. Catalogue of Fossil Reptilia & Amphibia, pt. i (1888) p. 220. ⁸ Id. ibid. pt. iv (1890) p. 259.

⁹ Id. ibid. p. 261.

¹⁰ Id. ibid. p. 262.

those of Iguanodon, atherfieldensis. Lydekker in 1888 1 assigns a sacrum (Brit. Mus. No. R. S11) to I. dawsoni, but in 1890 2 he transfers it to I. hollingtoniensis; and, if this determination be correct, then I. atherfieldensis has one more vertebra in the sacrum than the former.

In the early caudal vertebræ of I. atherfieldensis the neural arch is much lower and narrower, the prezygapophyses are directed forwards at a lower angle, the chevron-facets are of greater extent and set at a higher angle, and the notch of the ventral border is narrower than in either of the caudal vertebre of the type-specimens of I. mantelli, or of the caudal vertebræ ascribed to I. bernissartensis. The articular ends of the centrum are quadrate in I. mantelli, and wedge-shaped in I. atherfieldensis. the former the ventral surface is markedly different: not only is the notch much more open, but there is, in addition, a prepostaxial median concavity with highly convex borders continued to each extremity, and the chevron-facets are distinct and separate; whereas, in the latter, the surface within the notch is convex, and the chevron articular facets are not divided.

According to Prof. Dollo, the atlas and the last dorsolumbar do not bear ribs in I. mantelli and I. bernissartensis, and therefore in this respect I. atherfieldensis differs from both.

Appendicular Skeleton.

The scapula differs from that of I. mantelli or I. bernissartensis in possessing a greater expansion of the distal end and a greater slenderness in the median region, relatively to its length. Thus its length is 9 times its minimum width, whereas in I. mantelli it is 8 times and in I. bernissartensis 6 times. The superior border is not so much curved as in those two species. In this and other particulars it is near to the scapula of Camptosaurus.

The deeply excavated posterior border of the coracoid agrees with that of I. bernissartensis, but differs from that of I. mantelli, where, according to Prof. Dollo,3 it is distinctly convex. complete foramen agrees with that of I. mantelli, but differs from

that of I. bernissartensis, where there is a groove only.

I. atherfieldensis agrees with I. mantelli, in that the length of the fore-limb is a little more than half that of the hind-limb, and differs from I. bernissartensis, where it is two-thirds of the length. There is no essential difference in form between the humerus, radius, and ulna of the three species; they vary only in length. In I. atherfieldensis they are relatively shorter than in I. mantelli or in I. bernissartensis.

The number of elements in the carpus is not known in any other species of Iquanodon.

Brit, Mus, Catalogue of Fossil Reptilia & Amphibia, pt. i (1888) p. 199.

² Id. ibid. pt. iv (1890) p. 263.

³ Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) p. 162.

The one conical spur-like phalanx of the 1st digit of I. atherfieldensis is more reduced in size than in either I. mantelli or I. bernissartensis. In the first species it is a quarter of the longest finger; in the second, scarcely a third; and in the third, half of the length. In the first species the fifth finger does not diverge outwards at so great an angle as in the other two species.

In length the metacarpals are intermediate between those of I. mantelli and I. bernissartensis; but they are subquadrangular in section like the latter, and not laterally compressed as in

I. mantelli.

The proximal phalanges of the manus in I. atherfieldensis are relatively longer than in I. bernissartensis, and much more constricted laterally. In the latter they are subquadrangular. Those of the second row are also relatively much longer in the former than in the latter. The phalanges are closer in form to those of I. mantelli.

The length of the preacetabular process is nearly equal to half of the length of the ilium, as in I. mantelli, thus differing from I. bernissartensis, where it is equal to one-third. This process agrees with that of I. dawsoni in possessing a roof-like inner shelf. There is a greater convexity of the superior border in I. atherfieldensis than in either I. mantelli or I. bernissartensis. reflection of the superior border in the former and its extent are very much less than in the other two species. In I. dawsoni, I. fittoni, and I. hollingtoniensis the reflection is absent. depth of the ilium between the superior and acetabular borders is greater in I. atherfieldensis than in I. mantelli or I. bernissartensis, but very much less than in I. dawsoni or I. fittoni, where it is very In I. atherfieldensis the length of the postacetabular extension equals the depth from the dorsal border to the lower angle of the pubic process, as it does in I. mantelli. In I. bernissartensis it is only one-half. It differs from that of I. dawsoni by its shallowness and its angular distal extremity.

The ventral contour of the ilium differs from that of I. fittoni. The pubis is shorter than in I. mantelli or I. bernissartensis. It differs also from that of I. mantelli in the greater expansion of the distal superior border, and in the absence of expansion of its distal inferior border. In I. mantelli both borders are equally expanded, and the vertical diameter of the distal expansion is much greater than in I. atherfieldensis. In the latter the superior border is concave, and the inferior border nearly straight, while in the former both borders are concave. In I. bernissartensis they are

straight.

The femur is shorter and more curved than in I. mantelli or I. bernissartenis. In I. mantelli and in I. atherfieldensis the inner trochanter occurs in the median region of the shaft, and in I. bernissartensis in the lower third.

The tibia of I. atherfieldensis is relatively shorter than in I. mantelli, and longer than in I. bernissartensis.

There does not appear to be any essential difference in form between the fibulæ of those species in which that bone is known.

According to Dollo's ¹ figure, there is a greater separation of the distal extremities of the third and fourth toes in *Iguanodon mantelli* and *I. bernissartensis* than in *I. atherfieldensis*.

IV. Conclusions.

It has been demonstrated that *I. atherfieldensis* is distinct from any known species of *Iguanodon*, that the skull is intermediate in form between that of *I. mantelli* and *I. bernissartensis*, and that the bones of the remainder of the skeleton manifest the same characteristic. The different relationship between the bones of the skulls of the three species is doubtless, in some measure, due to the obliteration of the sutures by age, and to the compression to which the skulls of *I. mantelli* and *I. bernissartensis* have been subjected. Future discoveries may prove that in those species all the presacral vertebræ carry ribs, but the preaxial curvature of the diapophyses of the late dorsals, and the ribs that they bear, may be peculiar to *I. atherfieldensis*.

The relationship of the lateral elements of the skull, the fact that all the presacral vertebræ carry ribs, the form of the scapula, the notching of its internal proximal border to make a portion of the coracoid foramen, and the curved femur, are features showing affinity with Camptosaurus; but in the mandible of I. athertieldensis the surangular does not meet the dentary, nor the splenial the coronoid, as they do in that genus. The specialized teeth, the sacrum, the ossified sternum, the bones of the pelvic girdle, and the highly specialized hands and feet are characteristics of the

genus Iquanodon.

The free articulation of the quadrate with the squamosal, and its ligamental union only, is proved by the beautifully preserved articular surfaces. Baron F. Nopesa 2 has shown that in Telmatosaurus transylvanicus, the quadrate moved from the front to the back in the squamosal cotylus. He is of opinion that the backward movement of the lower jaw has at the same time a deeply rooted, important dissimilarity from that of the lower jaw of I. mantelli, in which the reciprocal slope of the biting surface of each single tooth excludes, as a matter of course, the possibility of such a movement from front to back. In I. atherfieldensis the free quadrate was also adapted for a fore-and-aft motion of the lower jaw. A fixed quadrate would obstruct such a movement. The obliquely worn crowns of the functional upper and lower teeth, far from preventing, are the natural effect of, a to-and-fro horizontal trituration. There was also a vertical biting action of the mandible, for the vegetable food, having been browsed by the horny beak, was submitted to a further chipping by the teeth before mastication. It appears certain, therefore, that there was

¹ Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) pl. v.

² Denkschr. K. Akad. Wissensch. Wien, vol. lxviii (1900) p. 574.

a similar forward and backward movement of the lower jaw in *I. atherfieldensis* as in *Telmatosaursus transylvanicus*, and the reason why this cardinal feature has been unobserved before in the Iguanodonts is because matrix has fixed the quadrate in the

squamosal.

The capacious and elongated cavity on the ventral surface of the anterior ray of the jugal, which overlaps the powerful jugal process of the maxilla, and the excavated articular surface of the median ray of the jugal for the reception of the postfrontal process, strongly suggest that a slight movement of these bones was also possible. All their articular surfaces are perfectly smooth. The posterior ray of the jugal is extremely thin, and, although it reaches the anterior border of the quadrate, it is not in the same plane. The hinder border of the jugal overlaps the quadratojugal, and the latter bone possesses a wide groove on its posterior border, into which the antero-exterior border of the quadrate was received; therefore no obstacle to a slight movement of the elements of the postero-lateral regions of the skull is to be observed.

The floor of the mouth in the median region of the mandible is so much constricted by the expansion of the internal walls of the dentary bones that the rami are only 40 mm. apart and, as the maxillaries are separated by about the same distance and have vertical inner surfaces 50 mm. high, the passage to the gullet is a remarkably compressed and elongated funnel. It is difficult to understand how food was carried along this narrow passage, for the swelling of the dentary walls proves that only a very narrow tongue could have occupied that region. Contrasted with this is the widely-open 'spout-like' symphysial cavity, where the tongue must have been very broad. The cheeks would exert the necessary inward pressure to assist the food being brought into mastication, but fresh supplies could only have been drawn in by the fore-andaft action of the mandible, assisted by the broadly-tipped prehensile tongue, which propelled backwards the vegetable matter chipped off by the horny beak and received into the capacious symphysial cavity.

The peculiar pre-postaxial narrowness of the neural arch of the 9th cervical vertebra is apparently connected with the flexing of the neck, for the facets of the prezygapophyses look, not only inwards, and upwards, but backwards in the 6th, 7th, 8th, 10th, and 11th cervicals and 1st dorsal, and in a very marked degree in the 9th cervical. In the 2nd dorsal they look upwards and inwards, and continue thus to the sacrum. It seems clear, therefore, that the neck of this *Iguanodon* was not only flexed habitually, but that the point of greatest arching was at the

9th cervical.

The preaxial curvature of the diapophyses of the last five dorsal vertebræ, and of the short ribs which they carry, is apparently the result of the habitual bipedal attitude assumed by the reptile, which caused a muscular stress upon them by the weight of the trunk, and was also the main factor in modifying the bones of

the sacral and pelvic regions. Thus the pubic bones were prolonged preaxially, and the distal ends of the ischia were bent forwards. and united to form a crutch or cradle-like support. Again, in the sacrum the first five sacral ribs are directed downwards at an angle of 45° to the vertical axis of the centra, so that each centrum forms the keystone of an arch formed by the opposite pair of sacral ribs, and each of these ribs is buttressed by the stout vertical walls of bone, which are fused to them and to the ventral borders of the diapophyses. This compact and efficient adaptation was to counteract the great upward thrust exerted by the pressure on the ilia of the femora, when they supported the whole weight of the body of the reptile on its assuming a bipedal attitude. Interiorly, the pubic peduncle of the ilium is produced into a shelf of bone, which underlies the expansion of the 1st, 2nd, 3rd, and 4th sacral ribs. The postacetabular portion of the ilium is closely applied to the remainder of the sacricostal voke (fig. 6, II, p. 28). Moreover, the diapophyses abut against the vertical inner wall of the ilium, and the preacetabular process of the ilium overlaps, with its inner shelf-like production, and is in union with. the expanded summit of the second diapophysis. The ilium is thus firmly buttressed by the sacrum.

The prolongation of the articular surfaces of the distal condyles of the femur and the proximal condyles of the tibiæ on to the postaxial surfaces of the condyles is an arrangement that permitted the reptile easily to assume a squat position, and suggests that, during quadrupedal walking, the hind limbs were considerably flexed at the knees. In fact such an attitude was necessary, for the bracing of the vertebral column by the ossified tendons would not have allowed of the great arching of the back that otherwise

would have been needed.

The bending forwards of the lower half of the tibiæ proves that the lower part of the hind legs was directed forwards, and their articular surfaces manifest that they were slightly splayed outwards.

EXPLANATION OF PLATES I & II.

PLATE I.

The right ramus of the mandible, from the symphysis to the coronoid process; inner view, showing six successional teeth, the alveolar parapet, the neural foramina, and the two alveoli on the coronoid process. One-half of the natural size.

PLATE II.

[All the figures are approximately one-half of the natural size.]

- Fig. 1. Impression of the epidermis from the left ilium, exhibiting small convex tubercles.
 - A small fragment of matrix, with the impression of the epidermis.
 A fragment of matrix exhibiting the under surface of the epidermis.
 - 4. Fragment of the matrix with impressions of two large polygonal tubercles.
 - A cluster of large, feebly convex, polygonal tubercles continuous with small convex tubercles, on a block of matrix removed from the exterior surface of the proximal end of the right ulna.

QUART JOURN GEOL. SOC, VOL. LXXXI. PL. I.



IGUANODON ATHERFIELDENSIS, sp.nov.

ZINCO COLLOTYPE CO. EDINBURGH





ZINCO COLLOTYPE CO. EDINBURGH



DISCUSSION.

Dr. C. W. Andrews said that the death of Mr. R. W. Hooley was a very great loss, not only to those who had the good fortune to know him personally, but to the science of Paleontology. He was one of the most successful of that remarkable band of enthusiastic amateur collectors to whom we owed most of our knowledge of the fossil reptiles of this country. It was difficult to imagine what our position would have been without such men as Mantell, Fox, Hulke, Dawson, Leeds, and Hooley, to mention only a few. All these were busy men who devoted their leisure to palæontological work, and it was to be hoped that the succession would remain unbroken.

Prof. D. M. S. Watson said that he could only follow the previous speaker in expressing his poignant sense of the great loss suffered by Palæontology in the decease of Mr. Hooley. The band of amateur naturalists who had accomplished vastly important scientific work constituted one of the glories of this country.

2. The Fossil Elephants of the Upper Thames Basin. By Kenneth Stuart Sandford, M.A., Ph.D., F.G.S. (Read March 26th, 1924.)

[PLATES III-VI.]

CONTENTS.

		Page
I.	Succession of Deposits: Recent Developments	62
II.	Notes on Tooth-Measurement: Method adopted	66
III.	Elephas antiquus Falconer and Forms allied to E. tro-	
	gontherii Pohlig	69
IV.	Elephas primigenius Blumenbach, Ilford and Siberian	
	Varieties	80
V.	Summary and Conclusions	
	Bibliography	

I. Succession of Deposits: Recent Developments.

In a paper published recently in the Journal of this Society (Q. J. G. S. vol. lxxx, 1924, p. 113) I described the river-gravels of the Thames and of its tributaries about Oxford, and, on a considerable body of evidence, suggested the following sequence of events:—

Glacial Plateau Drift; about 140 feet above the present river-level.

['Glacial', because, among other things, it contains glacially-striated erratic boulders and pebbles.]

Handborough Terrace; base about 90 to 100 feet above river-level, containing a well-marked 'Elephas antiquus fauna'.

Wolvercote Terrace; about 40 feet above river-level, with derived Chellean implements, no fauna known; placed later than the above on stratigraphical evidence.

Wolvercote Channel; about 40 feet above river-level, a 'ravinement' of the Wolvercote Terrace, containing at the bottom unrolled Upper Acheulean and Micoque implements, *Elephas antiquus* and associated animals, capped by sands with mollusca indicative of temperate climate, and at a higher level peat, with plants, mosses, and coleoptera of temperate to sub-arctic character; above are clays containing rare implements, which are suggestive of Mousterian workmanship. At the top the Warp Sands are driven into the underlying deposits, as if by considerable force from above (suggestive of a cold and wet climate).

Summertown-Radley Terrace; about 20 feet above river-level, separated from the Wolvercote Terrace by a step; lower gravels abundant in remains of *E. primigenius* and accompanying fauna (less the Reindeer), overlain unconformably by gravels in which occur Hippopotamus, sometimes abundant, *Corbicula fluminalis*—occasionally very abundant, with valves united and in place of growth, *Elephas antiquus* and other mammals which usually accompany it. Rolled Chellean and (Lower) Acheulean implements occur (though rarely) in this twin terrace; no unabraded specimens are known.

It seems clear that the lower deposits of the Wolvercote Channel and the upper gravels of the Summertown-Radley Terrace are of much the same age.

Sunk Channel and Flood-Plain Gravels; their summit is about 10 feet

above river-level, descending to about 30 feet below it; no fauna or industry known definitely, possibly *Elephas primigenius* occurs.

Alluvium; capping the Sunk Channel unconformably, and resting at the foot of the Flood-Plain Gravels.

Since the above paper was written, some evidence has appeared of an equivalent of the Warp Sands of Wolvercote resting on the top of the Summertown-Radley Terrace. On a patch of gravel (about a mile from Abingdon on the Radley Road) a depth of about 4 feet of highly ferruginous and decalcified sand, including some pebbles, has been exposed; the junction is rather irregular, with pockets, but is not contorted—although, as the gravel-spread is one of some square miles and perfectly flat, no movement is likely to have occurred, as on a small isolated plateau (Wolvercote, and Pear Tree Hill which adjoins it). The ferruginous sand is probably only the decaleified remains of normal gravel, but such a feature has not been seen elsewhere in the district; with it may be connected 'solution-festoons' and pockets-accompanied by partial decalcification—which are a common feature of the uppermost few feet of the gravel, both of this and of the Handborough Terrace.

It is impossible—certainly at present—accurately to fix the age of the decalcification; but the resultant, as seen in the pit near Abingdon, recalls, in appearance, the Warp Sands; if they are related—though the suggestion is little more than tentative—they serve as a deposit common to the top of the Wolvercote Channel and of the Summertown-Radley Terrace—and one which has not been observed in the gravels of the Sunk Channel or of the Flood Plain.

At the moment of writing, some information of vital importance has come to light, thanks to Mr. J. Wilfrid Jackson, of the Manchester University Museum. Mr. Jackson, to whom my sincere thanks are due, reported to me a 'lost' Oxford collection—that of the late Mr. Manning-which many years ago found its way to the above-mentioned Museum. I have studied the collection, which is well displayed; it makes most valuable additions to the fauna of the Wolvercote Channel—in particular, it supplies four more teeth of Elephas antiquus, all excellent specimens; it also identifies the species of Rhinoceros—Rh. leptorhinus—already known from the bottom of the Channel, but generically only-and adds Bear, and above all Reindeer. This is the first specimen of true Rangifer tarandus that I have identified from the Upper Thames; although it had been reported, no specimens have been preserved to verify the reports (which themselves are rather vague) (2). Its apparent absence had caused comment in my previous paper. This unique specimen is undoubtedly a true example of the antler of Rangifer tarandus; but, further, it appears to be of the 'barren-ground type' of Scharff (3). It is doubtful whether the varieties of Reindeer are so simple as that author suggests; but, at least, it seems clear that two types occur in this country—an earlier, of the above type, which is not

¹ Numerals in parentheses refer to the Bibliography, § VI, p. 84.

necessarily of Arctic habitat, and a later invasion of the 'woodland type' from Siberia. Of the living Reindeer and Caribou there appear to be more intermediate forms between these two extremes than Scharff suggests: thus, although the Spitsbergen and Scandinavian forms are doubtless of the 'barren-ground type', as opposed to the 'woodland type' of America and Siberia, there is a strongly marked dissimilarity between them. The antlers of the Spitsbergen type, which is much the smaller, tend towards the woodland type.

Unfortunately, of the specimen from Wolvercote the upper times are missing, and we have but the main beam from which

to judge.

After a close study of the specimen and of the small quantity of adhering matrix, I am of the opinion that it did not come from the ferruginous and calcareous gravels at the bottom of the Wolvercote Channel, but from the overlying sands and silt.

There now can be little doubt as to the occurrence in situ in the basal gravels of the Wolvercote Channel of Elephas antiquus, and it becomes increasingly clear that these and the upper (E. antiquus) gravels of the Summertown-Radley Terrace are of almost identical age: with regard to the more exact relations of the two deposits, the evidence is as follows:—

(1) Both deposits are younger than the Wolvercote Terrace

gravel.

(2) Probably both are older than the non-fluviatile Warp Sands.

(3) It is unlikely that both, with their present difference of level, could have been laid down simultaneously by the same river, or by meanders or cross-streams from it.

(4) A glance at the map shows how little room there is for a small tributary between the Thames and the Cherwell, even including the whole width of the flood-plain. Such a stream would have been flowing on much higher ground between the two rivers, with a small collecting-ground almost entirely surrounded by a lower flood-plain, and its gradient would have been very steep. There is little to support the suggestion.

(5) Turning to the vertebrate fauna, we find *E. antiquus* common to both deposits, also Red Deer and other manmals; but it is significant that Hippopotamus has not been found at Wolvercote, although it is frequent in the (upper) Summertown-Radley Terrace—where it occurs lying on eroded gravels containing the

² Possibly this is due to interbreeding with individuals from Novaya Zenilya, which are now known to make their way over the pack-ice to that remote archipelago (5).

¹ Dr. Marcellin Boule (4) found Reindeer, apparently of this type, during his work in the caves of Grimaldi; he took it to indicate a fauna of cold habitat, but it seems unlikely that this region can have suffered a really severe relapse of climate. The discovery was made in deposits with Magdalenian implements, beneath which are others of Mousterian age containing Mammoth and Woolly Rhinoceros, but apparently no Reindeer. There was probably considerable 'lag' in the arrival—and that only spasmodic—of northern types in the South of France.

Siberian Mammoth, as well as the older Hford form, and the

Woolly Rhinoceros: this is a remarkable fact.

(6) The evidence of implements becomes convincing; we have unrolled specimens in the basement-gravels of Wolvercote, of Upper Acheulean and Micoque industries; despite continued search, no type more advanced than Lower Acheulean and Chellean, in a rolled state, is found on the lower terrace.

(7) The mollusca: we have none from the actual basement-bed at Wolvercote, but they are found in sands a little above it. It is to be noted at once that Corbicula fluminalis is absent, though frequent in the terrace under discussion. Mr. A. S. Kennard &

Mr. B. B. Woodward (1, Appendix III, p. 175) say that

' Unfortunately, the Wolvercote shells are a featureless group, all the species belonging to living forms; but, if we may judge from the form of Fruticicola (Capillifera) hispida (Linné), which is present, the Wolvercote deposit (that is, the channel) is probably older than the others. The shells are all well developed, and the climatic conditions in both stages were clearly similar to those of the present day, with the possibility that the later deposits may represent a slightly warmer phase."

By 'later' the Summertown-Radley Terrace is indicated—this in the opinion of the authors cited, with the then existing evi-

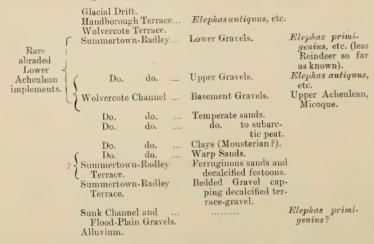
dence, being considered the younger.

(8) The Wolvercote Channel group, as it stands, is self-contained, and it remains for us to decide where it should be placed in a scheme of chronology. From the foregoing considerations, with the exception of the instance quoted-which the authors cited do not seem to have regarded as very conclusive, -I think that the burden of evidence points to the basement-gravel of the above group not only being of very much the same age as the upper gravels of the Summertown-Radley Terrace, but probably younger than they are. The stratigraphical difficulties then become clear, for there now appears a close continuity from the above-mentioned terrace, through the basement-gravels of the Wolvercote Channel, to the sands of definite temperate character, temperate to subarctic peat, and the overlying heavy clays (with rare implements of Mousterian-like type). We have, then, a period of aggradation. The next phase was one of erosion, leading, possibly with one pause, to the excavation of the Sunk Channel and Flood-Plain, probably accompanied by the formation or initiation of the Warp Sands and phenomena of decalcification.

(9) There are indications that, in the progress of the erosion just mentioned, there was a pause at the present summit of the Summertown-Radley Terrace. The uppermost few feet of gravel are frequently disordered, and marked by 'solution-festoons'; but at Summertown the zone is capped by a foot of quite undisturbed, well-bedded gravel-which was most probably deposited after the top of the terrace-gravel was thrown into disorder (by surfacesolution or possibly by solution under water). At Eynsham an extensive spread of fine gravel, some 4 feet thick, lies unconformably on the Upper (warm fauna) Gravels, and contains bones in a

much fresher state than those of the terrace-gravel.

The following would, then, seem to be the sequence of events:-



In the following pages, in which the Elephants are treated from a palæontological point of view, the collection of the Manchester University Museum will be referred to separately at appropriate

places.

Before passing on, I wish to express my keen regret—which is that of all geologists and paleontologists—at the recent death of Dr. C. W. Andrews. His name will be found frequently in the following pages, which were read by him at my request not long before his decease; the paper owes its inception to him, and his correction of it was among the last of his labours.

II. NOTES ON TOOTH-MEASUREMENT: METHOD ADOPTED.

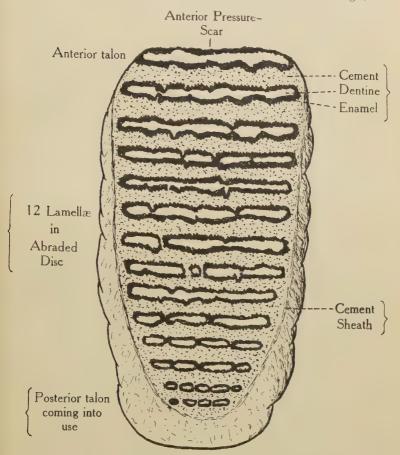
Method of Calculating Length-Lamellæ Ratio and Lamellar Frequency (see text-figure, p. 67).

Length-lamellæ ratio. The process of obtaining the length-lamellæ ratio, by dividing the length of the tooth by the number of plates, is not always a simple matter: in this paper the elaborate system adopted by Sörgel is not followed in full.

The following points should be noted.

An elephant's tooth consists of a number of enamel folds or plates, each with a median portion of dentine, separated one from the other by bands of cement; each plate has its contiguous band of cement; at each end of a complete molar is a small end-plate or talon, and the whole is encased in a wrapping of cement. For purposes of measurement a complete fold is taken to include enamel, dentine, and a zone of cement; the talon on its outer side has only the general encasing cement, and that indeed is only

present so long as it is not forced out by pressure against the anterior tooth, or from the tooth at the rear. If we consider a tooth of the formula $x \, 12 \, x$ (x representing the talon) we note twelve complete folds, with cement before and behind, and two talons each with cement which is adjacent to the next ridge; in



Molar entirely in wear. Semi-diagrammatic.

calculating the length-lamellæ ratio we take the plate-number as 13 not 14, and divide the length of the tooth by this number, so obtaining the required ratio.

But, with a tooth lacking one talon, -12x, we note the same number of complete plates with their cement and the rear talon,

which cannot be counted as a complete plate in obtaining the

ratio; 12 is used as the plate-number.

Similarly, if both talons are missing, -12-, there are still twelve actual plates of enamel and dentine, with eleven zones of cement between them, and probably vestiges of cement bordering the outer surfaces of the terminal plates; in this case the platenumber is still taken as twelve.

In the second and third cases the method adopted is not strictly accurate; but the error is, at the most, only one of a few millimetres and within the error of measurement and the unavoidable error governed by the condition of preservation of the tooth. Thus, although absolutely accurate results are not obtained, they are probably within the degree of error of practical work, and affect only the second place of decimals or the first by one unit.

It is held that any result approximated to the nearest integer is accurate enough for practical purposes, at least when we are dealing, as in this case, with the large amount of material derived from gravel, mostly damaged slightly either in incorporation, or while buried, or in removal from a deposit. In dealing with perfect specimens from cave-earth or læss, more accurate methods might well be employed; but, in the present case, a false accuracy would be obtained.

Lamellar Frequency.

The lamellar frequency—that is, the number of plates contained in 10 centimetres—has been found from the plate-number multiplied by 100 and divided by the length (in millimetres); in this way an average of the tooth is obtained, and not the frequency of any 10 cm. chosen; this is found to be as accurate as taking several measurements of frequency on the same tooth, and using an average of these results. The process, then, is as follows:-

Molar of x 12 x, length = 730 mm.:-In 730 mm. are 13 complete plates; ... in 100 mm. are $\frac{13 \times 100}{730}$ complete plates = 10.78;

or, within the accuracy of measurement and state of preservation of the tooth, 10.8.

Under 'preservation' is included the shrinkage or expansion of the tooth, owing first to incorporation for a long period in a superficial deposit, and subsequent removal and preservation in a dry place; although this amount may not be great, it is nevertheless one of the sources of minor error that cannot be gauged.

The foregoing explanations are given, in order to avoid misunderstanding, and to make quite clear the methods adopted, with their merits and limitations.

III. ELEPHAS ANTIQUUS FALCONER, AND FORMS ALLIED TO E. TROGONTHERII POHLIG.

Remains that can be assigned to *Elephas antiquus* are not abundant in the Oxford district; but its presence is beyond all dispute, and the specimens in the University Museum are particularly well authenticated: they are, therefore, of unusual importance.

There are about a dozen known to me; and of these three must

be excluded, as all trace of their origin is lost.

With the exception of the tip of a tusk from Hurley, all the remains are molars. The following analyses are arranged accord-

ing to the terraces in which the teeth occur.

Handborough, 'High' or 100-foot Terrace.—A most interesting collection of teeth came into the possession of the Oxford University Museum in 1919, through the care of the late Mr. Lay, a farmer of Long Handborough, near Woodstock; the teeth were found in a pit on his land, extracted under his own supervision, and there is no doubt whatever as to their occurrence in situ in this pit. They were the first mammalian remains to be discovered in the High Terrace within the Oxford district, and for their palæontological interest are worthy of description.

(Long Handborough, No. 2.) Third (?) true molar, lower.\(^1\) (Pl. III, fig. 1, & Pl. IV, fig. 1.)

The tooth has a formula of x 10 x, and is entire; the anterior talon is damaged, and the fangs are missing. All the plates, except the posterior talon (which is not exposed), are worn, and the median lozenge is not developed. Crimping is entire, but is not strongly marked.²

Length of crown = 220 mm.; width in front = 62 mm.; greatest width = S1 mm.; height at seventh plate = 120 mm.

Length-lamellæ ratio = 20; lamellar frequency = 5.

The tooth has a ratio (20) which corresponds to the highest ratio given by Sörgel in his Table VII (q.v.) for *Elephas antiquus*. The late Dr. C. W. Andrews described the tooth, after he had examined it, as *Elephas antiquus* of archaic type.

(L.H. No. 1.) Third (?) true molar, lower. Very similar to L.H. No. 2, and, although there is no proof,

¹ The fact that there is no trace of a posterior pressure-scar leads one to suppose that this tooth is a third true molar; but, on the other hand, a

formula of x 10 x is more in harmony with a second molar.

² G. Pontier (q.v.) calls particular attention to the condition of crinkling (festonnement) of enamel in teeth of E. meridionalis and E. antiquus; in the former the festonnement does not as a rule reach the size of the enamel-band. The relief seems added to the plate; in the latter (E. antiquus) the whole band of enamel is folded; the former condition I define as superficial crimping, the latter as entire folding. This feature should be noticed in a tooth of such archaic character as this molar and the next (L.H. 1), although both are undoubted specimens of Elephas antiquus.

there is some reason for believing that the two teeth might have

belonged to the same individual.

Only about half the tooth is preserved, including eight plates and the posterior vermiform talon, which, as in the first tooth, is not visible on the worn crown of the tooth. Median lozenge not developed. Crimping as in L.H. No. 2.

Length preserved = 157 mm.; greatest width = 75 mm.; greatest height = 120 mm. Length-lamellæ ratio = 19.6;

lamellar frequency = 5.1.

Unworn plates of both teeth show four cusps, the two inner being the larger, and, with wear, being the first to unite, the outer cusps remaining separated for some time.

(L.H. No. 4.) Third or last true molar, lower. (Pl. III, fig. 2, & Pl. IV, fig. 2.)

Unfortunately, this tooth is incomplete; but, even so, it is a

very striking specimen.

The posterior talon, with probably more than one ridge, is missing; a fragment of the anterior talon and 13 ridges (12 worn) remain. A separate fragment containing three unworn and one broken lamellæ undoubtedly belongs to the tooth, but cannot be rejoined with accuracy. The tooth, then, probably had a formula of x 16 x or x 18 x; but only the main part with 13 lamellæ will be considered. The median lozenge is developed in the anterior lamellæ, and the first lamella has broken into the talon on the median line. The enamel folding is entire, and strongly marked on the external surface of each plate. Length preserved = 250 mm.; width in front = 56 mm.; greatest width = 81 mm.; height of ninth plate = 165 mm. Length-lamellæ ratio = 19·2; lamellar frequency = 5·2.

The tooth has many features in common with *Elephas antiquus* B of Leith Adams (q.v.): its length-lamellæ ratio associates it rather with *Elephas antiquus*; but its breadth and its probable length when complete give grounds for referring it to *Elephas*

antiquus trogontherii Pohlig.1

A feature of this and the next tooth (L.H. 3) is that unworn plates, instead of possessing well-separated cusps, have up to six (possibly more) small lobes, all of much the same size, which come into use almost simultaneously.

For the present, under the guidance of the late Dr. Andrews, the specimen is referred to *Elephas antiquus*; but it may be considered a trogontherian form.

(L.H. No. 3.) Unworn upper third (?) molar.

The talons are missing; twelve ridges are preserved, and the complete tooth had a formula probably not greater than x 14 x. As the crown is quite unworn, no analysis of the disc is possible. The ridges are very massive and well spaced.

¹ See W. Sörgel, Palæontographica, vol. l (1913) pl. ii, figs. 2 & 4.

Length preserved = 230 mm.; width in front = 65 mm.; greatest width = 60 mm.; greatest height = 175 mm. Length-lamellæ ratio = 19.2; lamellar frequency = 5.2.

The tooth was classified by Dr. Andrews as Elephas untiquus

trogontherii.

(L.H. No. 6.) Three lamellæ, lower molar.

The worn surface of the plate shows the characteristics already enumerated for the tooth L.H.4 (*E. antiquus* or *antiquus trogontherii*); but crimping is not so strong, and there are only indications of a lozenge; the ridges expand rather rapidly towards the centre-line.

Length preserved = 59 mm.; greatest width = 70 mm.; greatest height = 81 mm.; length-lamellæ ratio = 19.7; lamellæ frequency = 5.1. Elephas antiquus, cf. trogontherii.

(L.H. No. 5.) Posterior talon and eight lamellæ, second (?) upper molar. (Pl. III, fig. 3.)

All the ridges are well worn, and the talon slightly so.

The tooth differs from those described above in many characteristics. The ridges are set much closer together, but are themselves fairly wide; the enamel is rather thinner, but is much crimped. Its folding is entire, and gives a fringe-like appearance to the external surface of the lamellæ; there is no true lozenge. The ridges are quite straight, and the crown recalls in some respects the general plan of the thick-enamelled Mammoth tooth.

No unworn plates are preserved, consequently no very sure idea

of the disposition of the cusps can be obtained.

It is unfortunate that this is the only specimen of a particularly

interesting type yet found in the district.

Length preserved = 127 mm.; greatest width = 70 mm.; greatest height = 104 mm. Length-lamellæ ratio = 15.9;

lamellar frequency = 6.4.

This is by far the lowest ratio that we have yet met; the height (104 mm., and that probably not the maximum height of the complete tooth with unbroken base) places it outside the range of any milk-molar of which I have seen figures. As a true molar its ratio (15:9) falls low for *E. antiquus*, but well within the range of *E. trogontherii* Pohlig, and to this species or variety it can with safety be assigned, on account of ratio, height, and breadth (the length is unknown), and worn lamellar pattern. Dr. Andrews, on seeing the tooth, remarked, while referring it to *E. trogontherii*, that it corresponds closely to the form of Mammoth known from the Ilford pits.

Only one other tooth has been discovered in the Handborough area: it came from a large pit about a quarter of a mile south of Lay's Pit, known as the Duke's Pit.

It is in the possession of Mr. J. Kibble, of Charlbury, and is damaged; but, while I was building it up from the fragmentary

condition in which it was found, it was seen to agree better with the tooth L.H. 4 than any other. The following are its chief features:—Lower true molar 80 mm. wide, 230 mm. preserved; maximum height = 115 mm. Owing to loss of cement between the lamellae, through damage, the ratio length-lamellae cannot be given with accuracy. Lamellae coarsely crinkled, but no true lozenge present. Talons missing.

Portions of a tusk were discovered in Lay's Pit, and were

removed by another collector.

This closes the list of Proboscidean remains yet known from the High Terrace in this district, and, I believe (6), west of the Chilterns; I believe also that it is the first definite evidence of remains of very definite trogontherian type in the High Terrace of the Thames.¹

Wolvercote 40-foot Terrace and Channel.—A number of heavy bones, mostly fragmentary, are known from the Wolvercote Channel; none has yet been found in the true Wolvercote Terrace.

Among the large collection of mammalian remains from Wolvercote in the Oxford University Museum only one elephant's tooth can be found: it came from the gravel at the bottom of the Channel; it is, however, of great importance. The late A. M. Bell (7) cites from Wolvercote Elephas primigenius, but not E. antiquus. I have been unable to find any trace of Mammoth from Wolvercote among the collections known to me, and, taking into consideration the fauna associated with the tooth, have come to the conclusion that Mr. Bell's specimens probably did not belong to the species E. primigenius Blum. It is not known on what remains he established the identification. Also, any fossil tooth of elephant, especially in past years, was apt to be classified as 'Mammoth' — later converted to 'Elephas primigenius', and allowed to rest at that. The same thing seems to have occurred to an important specimen from Wytham, which also proved to be of E. antiquus.

The tooth belongs to *E. antiquus*, and from its condition does not lead one to suppose that it is a specimen derived from an older deposit. In detail, it is as follows:—(Pl. IV, fig. 3.) Last upper true molar.—Parts of two ridges and their cement damaged, 14 ridges (10 in wear) and posterior talon, which is not exposed on the crown; traces of anterior talon. Crimping (entire) and enamel markedly heavy, lozenge well developed.

Extreme length of tooth = 220 mm.; length of crown in wear = 180 mm.; width in front = 45 mm.; greatest width = 72 mm.; height at tenth lamella = 173 mm. Length-lamella ratio = 14.7; lamellar frequency = 6.4.

The tooth has been identified by Dr. C. W. Andrews.

¹ Although its presence may be suspected at Swanscombe, Mr. H. Dewey ('Stratification at Swanscombe' Archæologia, 1913) reports a tusk more highly curved than that of *Elephas antiquus*.

The Manning Collection in the Manchester University Museum.

Teeth of Elephant from Wolvercote.—No records of depth are given, but all the teeth have considerable quantities of Oxford Clay adhering to the interior surfaces of the fangs and in other crevices; and there are definite traces—though not an abundance—of ferruginous staining, a condition common in material from the basement-gravel of the Wolvercote Channel and its junction with the underlying Oxford Clay. Moreover, the teeth correspond, in the condition of preservation, to the specimen described above and in general to the mammalian remains recovered from the basement-gravel. I have no hesitation in referring the teeth to this bed.

All are in excellent preservation; but the first two to be described are so perfect and unrolled that the cingulum, marking the position of the animal's soft fleshy gum with relation to the tooth and its various levels as it advanced, is perfectly preserved as a well-marked multiple ridge in the cement sheath.

I. No. L74 15 A.—A third lower molar, left side. x 13 x, x 11 in wear, in 170 mm.; total length = 230 mm.; breadth = 60 mm.; and height = 150 mm. The lamellar frequency is 6.5. and the ratio 15.4.

The median ridges show a well-developed lozenge; the first two ridges are quite straight, and the later lamellæ have not yet become complete. They invariably show the normal arrangement of a small circular cusp on each side of one of elongate or oval outline. Enamel somewhat thick and entirely folded; disc rather pear-shaped. The tooth is rather small and slight. *Elephas antiquus*.

II. No. L 74, 15 B.—A third lower molar of the right side. Also *Elephas antiquus*, and in appearance very similar to that just described. x 13 x, in wear x 11 in 160 mm.; total length = 240 mm.; breadth = 60 mm.; and height = 135 mm. The lamellar frequency is 6.9, and the ratio 14.5.

In this tooth the ridges are not so much worn as in the first; indeed, only the anterior talon and first two ridges are completely in wear with all the cusps joined; hence the lamellæ do not show the typical lozenge to advantage, although its presence is indicated in the second plate; behind, the unjoined cusps of each lamella are beautifully shown in perfect regularity in the system described above. In all other characteristics—enamel, disc, etc.—this and the preceding are identical, and might very well be opposite teeth of the mandible of the same individual.

III. No. L74, 14 B.—Another last lower molar, of the right side. x 1, 1 x, posterior talon not in wear. Total length = 205 mm.; in wear = 180 mm.; breadth = 60 mm.; height = 110 to 140 mm. with fang. The lamellar frequency is 6·1, and the ratio 16·3.

The first ridge and the talon are continuous on the centre-line. The lozenge is certainly developed in some of the central ridges. Except that the cement sheath is largely missing in this tooth, in all other respects it is similar in every detail to the two teeth already described; like them, it is rather small and slight.

IV. No. L74, 14 A.—The last tooth to be described is one of very great size; it is a third upper molar. x17 x, 12 lamellæ in wear in 220 mm.; the total length measured parallel to the plane of the disc is 330 mm. The breadth=80 mm. and the height=270 mm. The lamellar frequency is 5.5, and the ratio 18.3.

The size of this tooth is really astonishing. The anterior lamellæ are very massive, and do not show a lozenge; the 4th to 7th, however, do show it, though not very prominently. The enamel is very thick and coarsely plicated, and the ridges are very massive. This remarkable tooth quite dwarfs the upper ultimate molar in the Oxford University Museum, which is in harmony with the three lower teeth described above and with those from the Summertown-Radley Terrace and from Hurley, to be described shortly: all these will be found to form a clear antiquus-type of slight build and rather fine enamel; the lozenge is characteristic of them, and the cusp development so typical of E. antiquus is remarkably well displayed in a large proportion of them. The enormous tooth just described is exceptional, and reminds one rather of the coarse and massive molars of the Handborough Terrace, although its condition certainly does not lead one to suppose that it has been derived from that terrace.

Summertown-Radley Terrace.—In the Oxford University Museum there are only a few teeth of *Elephas antiquus* from this terrace; but it is surprising to find, on looking into the works of Falconer and Leith Adams, that all of them are described by one or both of these authors, though none has yet been figured.

The teeth are consequently of much importance, and I cannot do better than quote the descriptions of these two masters, adding

figures of some of the specimens.

It should be noted that none of them was labelled as a specimen described by Falconer or Leith Adams; but, having compared the measurements of the teeth and the records, in every case I find complete agreement. The dates of discovery, where known, and other details also agree, and there is no reason to doubt that these are the actual specimens.

A. Leith Adams, 'British Fossil Elephants' Monogr. Palæont.

Soc. 1877–1881, p. 21, says:—

^{&#}x27;Either a large last milk or an unusually small first true molar is admirably shown in a mandible from the gravels of Wytham, in the Oxford University Museum. The rami contain two fragments of molars with the two succeeding teeth in place; the right is entire, and holds x $11 \, x$ in 6.2 inches, thus displaying small proportions for the first true molar, which would be confirmed by the

dimensions of the fragments of the third milk in front; but I am not convinced that they belong to the same jaw, which is broken at the commencement of the diastem, where the fragments of the molars have been glued to the shattered surface. The entire molar has an arcuated crown, and the discs are clearly distinctive of the *E. antiquus*.'

The measurements and other details of the four teeth are as follows; it will be noted that each pair are almost identical:—

MM3 or M1:—Right Left	x 11 x	Length. 145 mm. 110 mm.	Breadth. 46 mm. 46 mm.		Ratio. 12·1 12·2
MM3 or MM2: Right Left	-6 x	72 mm. 72 mm.	43 mm. 43 mm.	8·3 8·3 (See Pl. V	12 12 7, fig. 4.)

Leith Adams did not describe the mandible. The break at the diasteme to which he refers is noticeable in the figure, but the broken edges are not too much damaged to prevent the jaw from being set up. The spine at the symplysis is damaged, but enough is preserved to show (though not well in the figure) the prominence, situation, and direction which is typical in this species. It would be remarkable if all four teeth and the two rami did not belong to the same mandible.

This is the only specimen of *E. antiquus* now preserved in the Oxford University Museum from the local Summertown-Radley Terrace (except probably a broken mandible, which will be described later); but its importance is very considerable, as at Wytham it was associated with *Hippopotamus* and other 'warm' animals which I have found in numerous exposures of the same terrace.

Another tooth, however, has come to light in the Manning Collection in the Manchester University Museum, and is from Summertown itself, though unfortunately no record as to depth has been preserved, It is as follows:—

No. L 74, 14 C. A large upper ultimate molar. —16 x, ten

No. L 74, 14 C. A large upper ultimate molar. -16 x, ten lamellæ to wear in 160 mm., total length parallel to the plane of the disc=280 mm.; breadth=70 mm.; and height=190 mm.

The lamellar frequency =6.25, and the ratio =16.

I think that this must be classified as *E. antiquus*. The plates are fairly broad, with entirely plicated enamel; and the lozenge is present, though not clear. In appearance, it is not unlike the molars of the Ilford Mammoth; but its frequency and ratio certainly associate it with *Elephas antiquus*.

There are excellent reports of teeth, which are now missing:—

(Leith Adams, op. cit. p. 33): [Elephas antiquus—true molars (third)].

'C Variety. The thick-plated variety is typically represented by a tooth from the Valley of the Thames, and referred to by the late Prof. Phillips (8).

It is from the low-level gravels at Culham, near Oxford, and is preserved in the University Museum. This superb specimen holds seventeen ridges,

besides a small vermiform talon on the inside of the last plate. The ridgetormula is x 16 x in 12.8 inches. The eight anterior ridges are invaded, showing large expanded disks with well-defined angulations, central expansions, and pronounced crimping of the macharides. The height of the ridges is enormous, that of the ninth being 9.5 inches, whilst the maximum breadth of the crown is 4 inches. I examined, moreover, in the Oxford University Museum, two fragments of a last molar holding two plates each. Both were also remarkable for the thickness of the enamel and dentine so characteristic of this type of molar. The specimens were found in Ballarat Pit, near Oxford,'

Culham tooth: length=about 325 mm; greatest breadth= 102 mm.; greatest height=242 mm. Length-lamellæ ratio=

19.2; lamellar frequency=5.2.

I know of no fourth or third terrace-gravel near Culham, but there is a very extensive low-lying platform of the second terrace, and there is little doubt that the tooth came from it, as it has long been worked on a big scale. It is very unfortunate that this tooth and the two Oxford fragments are not forthcoming.

Leith Adams regretted that he was unable to obtain a drawing

of this tooth.

The only other teeth of Elephas antiquus (also tip of tusk) come from a deposit which, I believe, corresponds to the Summertown-Radley Terrace of Oxford, at Hurley Bottom, near Henley. This is really outside my area of work, but the teeth mentioned from the Oxford University Museum call for a brief note.

Leith Adams (op. cit. p. 38) mentions a tooth in the Museum which I have not yet recognized. He calls it a good instance of a

broad upper crown:

'it is from Hurley Bottom, and entire, with a ridge-formula of x 16 x in 9.5 inches.'

=x 16 x in 242 mm.; ratio=14.2, and lamellar frequency=7. H. Falconer, in 'Palæontological Memoirs' 1868 (vol. ii, p. 177), refers to two teeth which I have been able to identify in the Museum:-

'In the Museum at Oxford there is also a specimen of the third left upper milk molar of Elephas antiquus, showing ten principal ridges with talons: five plates are more or less worn.

'Length of crown, 5.3 in. [=134 mm.]; width in front=2.05 in.; width behind=1.9 in.; greatest width=2.1 in. Height at fifth plate = 4.6 in.

[Ratio=12·1; lamellar frequency=8·2.]

'This is a very beautiful and characteristic specimen.'

Falconer gives no locality for the tooth; but the specimen now preserved in the University Museum, which coincides in every detail with the above description, comes from Hurley Bottom (Pl. V, figs. 2 & 3). (Op. cit. vol. ii, p. 179):—

'In the Oxford Museum there is a beautiful specimen of the third milk (or first true?) molar, lower jaw, left side: the crown quite entire, showing distinctly eleven main ridges, with front and back talons; seven ridges worn. The crown is narrow, and the enamel-plates are expanded in the middle.

'Length of crown=5.6 in.; width in front=1.8 in.; greatest width=2 in.; height at seventh plate=4 in.

'This specimen is from Hurley Bottom, Oxford,'

Length of crown=142 mm.; width in front=46 mm.; greatest width=51 mm.; height at seventh plate=102 mm. Ratio=11.8; lamellar frequency=8.4 (Pl. IV, fig. 4 & Pl. V, fig. 1).

This closes the list of type-specimens; but, before passing on, we may give attention to a broken mandible in the Oxford University Museum (830—'Old Angel, Oxford, 1877') (see Pl. VI, fig. 5). It consists of the left ramus, with the third true molar in place, but broken posterior to the tooth, with only a fragment of the coronoid preserved; part of the left ramus remains, with about one-third of the alveolus, but no tooth.

The specimen is remarkable in many ways: and, although it might pass for *E. primigenius*, there are many features which

lead one to classify it as E. antiquus.

Outline: the outer margin of the ramus from the anterior part of the coronoid to the spine at the symphysis is not a simple regular curve, as it usually is in *E. primigenius*, but is slightly

sigmoid (see fig.).

Diasteme: this region shows most markedly the variation from the primigenius type: being, when viewed in section, considerably more pronounced. The spine, though not actually at the extreme lower border of the symphysis, is very little above it, and is of considerable size: it is not like a superficial ossification, as it sometimes appears in primigenius, but both rami are shaped to form it. Thus the anterior margin of the jaw, instead of being almost semicircular, as in the true Mammoth, is pointed as a result of the junction of the two sigmoid curves (which are, of course, bilaterally symmetrical).

Viewed en face the 'spout,' instead of being almost semicircular in outline, is oval—thus making the region of the actual symphysis more slender than in normal *E. primigenius*—and in section oval, with the longer axis antero-posterior: in *E. primigenius* the longer axis would seem to be much more nearly vertical. Thus, incidentally, *primigenius* may achieve strength without the prominent spine which antiquus attains by a flatter section of the symphysis, with both rami tapering to form a very marked prolongation of the jaw in a forward and downward direction.

The top view of the mandible shows most of the above-described characters; in particular, the tooth, which should be a deciding factor. One thing can be detected at once—that the jaw belonged to an individual well advanced in years: for the surface of the tooth at the anterior end is so worn that the lamellæ have entirely disappeared, and the cement base and fang have been much abraded. Behind this region are eight ridges and the posterior talon: all are very well worn—in fact, the age of the specimen is the factor which may cause one to hesitate in referring it to E. antiquus; some of the characters may be of the nature of oldage modifications. The tooth, however, in its much abraded state is distinctly of antiquus character; eight ridges and the posterior talon are still in use in a length of 120 mm., giving a ratio of 15,

which is definitely within the range of *E. antiquus*: the frequency is nearly 7. The ridges are closely comparable to those of *antiquus*, and more nearly approach it than Mammoth; they are rather broad, with stout enamel which is entirely folded, and indeed show signs of a lozenge in the posterior ridges: there is a definite expansion along the median line of the tooth, and both ends of the ridges are turned slightly forwards. On the other hand, although the lamellæ are wide, they are set rather close together and the entire folding of the enamel is found in some teeth of *E. primigenius*, especially in the Ilford form, and in much-worn specimens like this.

The abraded disc tends to be of lozenge outline, rather than oval

or pear-shaped, as is so often the case in E. primigenius.

Lastly, a comparison of the measurements of this mandible with two of Mammoth, also in the Museum, gives the following figures (further details of the two mandibles are supplied on a later page). Breadth is measured along a line joining the anterior margins of the coronoids; length is measured from the breadth-line to the point of the spine, and the height is taken at the anterior margin of the alveolus:—

	Breadth.	Length.	Height.
S30 (E. antiquus?)		235 mm.	130 mm.
S33 (E. primigenius)	340 mm.	175 mm.	157 mm.
another $(E. primigenius)$ (without teeth)	400 mm.	160 mm.	140 mm.

The much greater length of the tooth under discussion is attained by the greater proportion of the part of the rami anterior to the alveoli, and the prolongation to form the spinal protuberance.

Viewing all the facts, one is certainly led to classify this interesting mandible as of *Elephas antiquus*, rather than of the Mammoth.

It is unfortunate that no record of level or occurrence is preserved with this specimen. The alveoli contain a considerable amount of fairly fresh Oxford Clay, which would suggest that it was found at the bottom of the gravel; but this cannot be taken as absolute proof, because it is known that the gravels under the city contain much more clay than they do elsewhere in the district (9). Also the uneven, and in places almost complete, erosion of the lower by the upper (antiquus) gravel brings the latter almost on to the Oxford Clay, as at Wytham and Magdalen College Grove (1).

Fauna accompanying Elephas antiquus.

Since the discovery of Elephant at Handborough I have recovered from the same patch of gravel:

Rhinoceros megarhinus or leptorhinus. Equus sp. (probably E. caballus). Cervus (?) elaphus. Bos sp. From the basement-bed of the Wolvercote Channel have been identified (and now preserved in the Oxford University Museum) with *Elephas antiquus*:—

Rhinoceros sp.

Equus caballus (with molar crown pattern of markedly simple character).

Cervus elaphus (with antlers of very great size).

Bos primigenius.

Bison priscus (?).

To which may now be added from the Manning Collection in the Manchester University Museum:—

Elephas antiquus (four molars).

Ursus horribilis (?), an ulna which has every indication of preser-

vation in unweathered Oxford Clay.

Rhinoceros leptorhinus (part of molar, clearly iron-stained).

Equus caballus (very numerous teeth, also bones).

Cervus elaphus (parts of numerous large antlers, also bones).

Bos or Bison (numerous teeth and bones).

The fauna at Wytham is now known to be, with *Elephas antiquus*:—

Hippopotamus major. Rhinoceros leptorhinus.

Kninoceros teptornini Equus caballus. Cervus elaphus. Sus scrofa.

From Hurley Bottom there are preserved with the teeth of *Elephas antiquus* in the Museum:—

· Felis leo spelæa (canine teeth).

Bos primigenius (molar and right humerus).

H. J. Osborne White (10), quoting from W. Whitaker's 'Geology of London,' adds:—

Hippopotamus,

Rhinoceros (species not stated),

Reindeer,

which 'have been found in the same kind of drift near Hurley.'

If the Reindeer is present at this site, it is an occurrence of interest and importance.

A molar of *E. antiquus* from Hurley is comparable to the Wolvercote teeth in every detail, the conformity between the two being very striking when they are placed together; similarly, the milk-molars of Hurley and Wytham show no variation. On the other hand, the Wolvercote teeth present a contrast to those from Handborough, being smaller and generally more delicately built.

It seems fairly clear that the species had become modified in some respects (presumably in size) during the long interval between the deposition of the Handborough Terrace and that of the Summertown-Radley and Wolvercote Channel deposits.

IV. ELEPHAS PRIMIGENIUS BLUMENBACH, ILFORD AND SIBERIAN VARIETIES.

In the Oxford district the true Mammoth is not met with, so far as my observations have shown, in any deposit above the 20-foot or Summertown-Radley Terrace; this in itself is a matter of importance.

The only specimen that approaches the Mammoth is the tooth from Handborough (L.H. 5) already described as Elephas tro-

gontherii Pohlig.

From Wolvercote E. antiquus only has been seen.

On the Summertown-Radley Terrace Mammoth abounds, often accompanied by Woolly Rhinoceros, and appears to be limited to the lower zone of the gravels. The thinly-enamelled Siberian variety is in overwhelming majority, but a few teeth of thick enamel have been found; it is this variety that Mr. M. A. C. Hinton recognizes at Ilford (11), the Siberian form apparently being a later comer; the few thick enamelled specimens in the Summertown-Radley Terrace show that the form had occupied the area.

Numerous teeth from the district are mentioned by Leith Adams (q.v.): of these some have been identified in the Oxford University

Museum, but others, it is feared, are missing.

The teeth of the Summertown-Radley Terrace, almost without exception, have straight narrow plates; wavy plates characteristic of the form Elephas primigenius trogontherii Pohlig have not been observed.

Uniformity is the most striking feature of upwards of fifty molars, a number of them quite complete, all from local deposits of the above-mentioned terrace, which I have measured and analysed in the Oxford University Museum; in the progress of the work all these have been numbered.1

The complete analysis of each tooth is not published, but it may be well to review the results obtained when the collection as a whole is considered.

Milk-molars.-No first milk-molars are preserved; but there is one second upper milk-molar (Coll. No. \$29, Iffley Drainage, 1874), mentioned by Leith Adams (Mon. Pal. Soc. p. 91), which has a formula of x 6 x, with a length of 55 mm., a lamellar frequency of 12.7, and a length-lamellæ ratio of 7.9 (Pl. VI, figs. 6 & 7).

Of the last milk-molar about half a dozen are preserved, mostly maxillary teeth; but only one is complete (S12), from the base of Webb's Pit at Summertown (near Oxford) :- x 9 x, with a frequency of 11.8 and a ratio of 8.5; length = 85 min. The abraded disc of all the above, where complete, is oval in outline.

True molars. Of the first true molar only one rather doubtful specimen is known (S11), a mandibular tooth from the same pit as the above (S12); it is x8- with a frequency of 8.4 and a ratio

¹ This includes a number of teeth collected by myself.

of 11.9, length =95 mm.; but another (S13) also from the same pit, an upper tooth, is probably a first true molar rather than a third milk-molar, and contains x 11 x in 117 mm., with a lamellar

frequency of 11.8 and a ratio of 8.5.

One excellent specimen of the second true molar (832) from the local gravel is preserved in a part of the maxilla; it is complete, with the formula x 15 x: its frequency is 10.9, and the ratio 9.2: it is, perhaps, rather broad for a second upper molar -67 mm., its length being 140 mm. This is the only undoubted second molar; there are two or three others which must remain doubtful because they are incomplete.

As usual, a large proportion of the teeth preserved are ultimate molars, and the University Museum is fortunate in possessing a

number in very good condition.

Third molars, upper.-Of these four are quite complete, and their measurements are as follows:-

S 27 (Yarnton, base of		Frequency.	Ratio.	Breadth.	Length.
gravel)	x 20 x x 22 x x 18 x	10 10·5 9	10 9.6 11	80 mm. 80 mm. 95 mm.	200 mm, 220 mm, 210 mm.
gravel)	x 21 x	10.5	9.5	74 mm.	210 mm.

The first two have straight narrow lamellæ, the last two rather wide lamellæ and thick, little-crinkled, enamel; the tooth S 15 is a magnificent specimen, and came from the bottom of the Summertown-Radley Terrace, near Drayton by Abingdon-from the near neighbourhood of the remarkable tooth of E. untiquus, now missing, described by Leith Adams from Culham.

The abraded disc of these, and of about half a dozen incomplete upper third molars, is pear-shaped to oval; the incomplete teeth display regular features: all have straight narrow lamellæ, and vary from -11 x to -19 x, the frequency and ratio varying from 9 to 11. If the length be divided by the maximum breadth, a mean ratio of 2.4 is obtained, the extremes being 1.7 and 2.7.

Lower jaws and third molars, lower.-The following are preserved in the Museum :-

1. S 33 (Oxford, base of gravel), a lower jaw containing the last molar of each side (Holywell Drainage, 1874); broken posterior to them, but with the left coronoid partly preserved (Leith Adams, Monogr. Palæont. Soc. 1877-1881, p. 106).

2. A lower jaw with the empty alveoli of the last molar of each side, broken behind the posterior margin of the alveoli. (From the foundations of the New Examination Schools, Oxford.)

Both the above are of fully grown individuals.

3. The region above the symphysis, but broken at or near the anterior margin of the alveoli of both sides. (Holywell Drainage, 1874.)

Q. J. G. S. No. 321.

Lower ultimate molars.—The teeth in the jaw S33 (above) are almost complete:—right, x14 x and left x15 x, with frequencies 9:1 and 9:4, and ratios 11 and 10:7 respectively: the lengths are 165 mm. and 160 mm.; the breadths, in the same order, 65 and 64 mm.

Three other complete teeth form, with the above, a very uniform set: all have straight narrow lamellæ; the abraded disc is oval,

tending to pear shape in one or two cases.

The measurements of the three teeth are as follows:

		Frequency	. Ratio.	Breadth.	Length.
S 2 (Yarnton, base of gravel)	x 19 x x 17 x	9·5 9	10·5 11·1	82 mm. 89 mm.	210 mm. 200 mm.
S 6 (Oxford), Old Angel)	x 17 x	10.9	9.2	68 mm; .	165 mm.

Lastly, there is a complete tooth of rather different character:

S 44 (Langford Lane) x 17 x 7.5 13.1 95 mm. 235 mm.

Twelve lamellæ are in wear in 160 mm. The enamel is thick and the lamellæ wide, crimping is very strongly marked; the tooth seems comparable to the Ilford form (Pl. VI, figs. 1 & 2).

With the above are some incomplete teeth and many fragments of Siberian form, and some which seem to compare favourably with the Ilford forms; the frequencies and ratios of these specimens, so far as can be estimated, agree well with the measurements tabulated above for the Siberian and Ilford forms respectively.

A molar from Summertown comparable to the Herd form is also included in the Manning Collection, at the Manchester University Museum.

'Bed of Cherwell.'

A particularly fine tooth (No. C1) is still exhibited in the Oxford University Museum, marked 'Bed of Cherwell, Oxford, 1866,' which was described by A. Leith Adams, in his Monograph (p. 115), in the following terms:—

'The only instance of an ultimate molar containing x 27 x that has come under my notice is represented by a specimen from the "bed of the Cherwell", in the Museum of Oxford University. The tooth is $10\frac{1}{2} \times 3$ inches, and contains eight ridges in a space of $3\frac{1}{2}$ inches. The enamel is thin, and the disk free from crimping.'

If we may judge by its condition, the tooth (Pl. VI, figs. 3 & 4) has been recovered from blue pyritous elay mixed with fine gravel; this suggests strongly that it was found near the Oxford Clay, in the silt beneath the river. The tooth is little abraded: a matter of importance, since its probable site is within the range of the Sunk Channel Gravels.

¹ Another molar tooth of Mammoth has been found at some depth, during the construction of a new railway-bridge at Kennington, near Oxford.

Lamellar frequency = 10.5; ratio = 9.5. Breadth = 79 mm., length = 230 mm., measured parallel to the plane of the abraded disc, the extreme length being 267 mm.

From time to time teeth of Mammoth and of Woolly Rhinoceros have been dredged from the Thames about Oxford, but on

these no reliance can be placed.

In the Summertown-Radley Terrace we note the apparent anomaly, which seems to be clearly established, of Elephas primigenius (abundant), also Rhinoceros tichorhinus and Bison priscus (rare), occurring with the greatest regularity in older basementgravels, surmounted by gravels which yield the 'warm' fauna:-Hippopotamus major; Rhinoceros leptorhinus and Elephas antiquus 1; Cervus elaphus; also Felis leo spelæa (of little climatic significance); and Corbicula fluminalis.

Rangifer tarandus is not yet proved in the Upper Thames in

this terrace, although it has been reported (2).

In both gravels of this twin terrace also occur: - Equus caballus and Bos primigenius. Cercus capreolus and Sus scrofa have

been reported (2).

From the older gravel a new species of Bear (one specimen), Ursus anglicus (12), is known, and I have found a single specimen of Cervus megaceros (believed to be from the upper gravel); this is its only occurrence in the Upper Thames.

V. SUMMARY AND CONCLUSIONS.

Geology.-As a result of recent work, evidence has been found which points to a period of aggradation in late- and post-Acheulean (Mousterian) times. It was preceded by a period of Elephus primigenius and, after some erosion, gravels of an ' E.-antiquus fauna' were laid down; in deposits of both these periods waterworn implements of Lower Acheulean age occur (Summertown-Radley Terrace).

The aggradation was carried on in the Wolvercote Channel, with the 'warm' fauna and Upper Acheulean and Micoque implements, and continued by sands and clays which indicate conditions increasingly temperate, tending to subarctic, with implements

which may be of Mousterian workmanship.

The aggradation seems to have been followed by an important period of erosion (to the Sunk Channel and Flood-Plain), accompanied by decalcification and the formation of the non-fluviatile 'warp sands', which may indicate a culmination of the lowering of temperature noted in the Wolvercote Channel. This development of surface-change is not found in the gravels of the Sunk Channel or of the Flood-Plain.

Palæontology.—The Elephants of the Handborough Terrace

¹ At Wytham itself only the 'warm' fauna seems to have been found, and the mention of 'Mammoth' from that site seems to refer to the mandible of Elephas antiquus already described, and not to E. primigenius.

are of particular interest, a mixture of archaic and Trogontherian forms, the first discovery of such in the Upper Thames, occurring

in the oldest fossil-bearing terrace.

The identification of E. antiques from the Wolvercote Channel is of considerable interest and value, since the species also occurs in the upper zone of the Summertown-Radley Terrace. The teeth from both these deposits form a clear type-rather small and of slight build, with the lozenge-shaped expansion of the worn lamella well developed; they are clearly of the species E. antiquus, but are in strong contrast with the massive and coarsely constructed teeth of rather archaic type found at Handborough. Some of the latter are equally of the species E. antiquus.

Elephas primigenius is first met with in the gravels of the Summertown-Radlev Terrace which have been overlain unconformably by the later antiquus gravels. It is represented by two varieties: the older Ilford form, thick-plated, which is in the minority, lingering side by side with the newer form of the Siberian invasion. The latter is abundant and markedly uniform in its characters, with numerous straight thin lamellæ. The form E. primigenius trogontherii of Pohlig has not been identified.

There is some evidence that the Mammoth occurs in the Sunk Channel, but more material is required to confirm this hypothesis.

The Oxford University Museum is fortunate in possessing a number of important specimens to which A. Leith Adams and H. Falconer have referred; some of these are now figured, with other teeth which call for particular attention.

VI. BIBLIOGRAPHY.

Works of General and Special Reference.

1868. H. FALCONEE. 'Palæontological Memoirs & Notes' compiled by Charles Murchison. London, 1868.

1877-1881. A. Leith Adams. Monograph on the British Fossil Elephants.

Pal. Soc. 1887. H. POHLIG. 'Ueber Elephas trogontherii & Rhinoceros merkii von Rixdorf bei Berlin' Zeitschr. Deutsch. Geol. Gesellsch. vol. xxxix (1887) pp. 798 et seqq.

1889. Do. 'Dentition & Kranologie des Elephas antiquus Falc., mit Beiträgen über Elephas primigenius Blum. & Elephas meridionalis Nesti' Nova Acta Acad. Nat. Cur. vol. liii (1889) pp. 5 et seqq. 1891-1893. K. A. von Zittel. Paläontologie, vol. iv, Mammalia. Munich, 1891-93.

1903-1904. C. W. Andrews. 'Evolution of the Proboscidea' Phil. Trans. Royal Soc. vol. oxevi B (1904) pp. 98-118.

1909. H. Pohlig. 'Ueber Elephas trogontherii in England' Zeitschr. Deutsch.

Geol. Gesellsch. vol. lxi (1909) pp. 242 et seqq.
1911-1912. G. PONTIER. 'Eléphants Quarternaires' Bull. Soc. Géol. France,

1912. G. ZAFFARDI. 'L'Elephas antiquus Falc. nella Filogenesi delle Forme Elephantine Fossili' Atti Accad. Linc. Roma, ser. 2, vol. xxi (1912)

pp. 298 et seqq. W. Schgel. 'Elephas meridionalis & Elephas antiquus trogontherii.' 1913.

W. SERGEL. Etephas meritionates & Etephas antiquis trogontherit. Palæontographica, vol. 1x (1913) pp. 1 et seqq.
H. Pohlig. 'L'Etage à Elephas trogontherit sur le Bas Rhin' Bull. Soc. Géol. Belg. vol. xxvii (1913) pp. 142 et seqq.
C. W. Andrews. Catalogue of the Elephants Living & Extinct, preserved in the British Museum. London, 1922.
H. F. Osborn. 'Pliocene & Early Pleistocene Mammalia of East Anglia' 1913.

1922. Geol. Mag. vol. lix, pp. 43 et seqq.

References in the Text.

- (1) K. S. SANDFORD. 'River-Gravels of the Oxford District' Q. J. G. S. vol. lxxx
- (1924) pp. 113 et seqq.
 (2) Sir Joseph Prestwich. 'On the Occurrence of Cyrena fluminalis at Summertown near Oxford' Geol. Mag. 1882, pp. 50 et seqq.
 (3) R. F. Scharff. 'History of the European Fauna' London, 1899, pp. 150
- et seqq.
- (4) M. BOULE. 'Les Grottes de Grimaldi' L'Anthropologie, vol. xvii (1906)
- pp. 257 et seqq.

 (5) A. Hoel. 'D'où vient le Renne du Spitsberg?' La Géographie, vol. xxx
- (1915) pp. 443 et seqq.
 (6) O. A. Sheubsole. On the Valley-Gravels about Reading, with especial reference to the Palæolithic Implements found in them' Q.J.G.S. vol. xlvi
- (1890) p. 592.
 (7) A. M. Bell. 'Implementiferous Sections at Wolvercote (Oxfordshire)' Q.J. G.S. vol. lx (1904) p. 120.
 (8) John Phillips. 'Geology of Oxford & the Valley of the Thames' 1871,
- p. 465. (9) Т. І. Россск. 'The Geology of the Country around Oxford' Mem. Geol.
- Surv. (Special Sheet) 1908, p. 87.

 (10) H. J. Osborne White. 'The Geology of the Country around Henley-on-Thames' Mem. Geol. Surv. (Sheet 254) 1908, p. 97.

 (11) M. A. C. Hinton, 'British Fossil Voles & Lemmings' Proc. Geol. Assoc.
- vol. xxi (1909-10) p. 491. (12) R. T. Gunthee. 'Ursus anglicus, a New Species of British Bear' Ann. & Mag. Nat. Hist. ser. 9, vol. xi (1923) pp. 490 et segg.

Note: The following have been published of late, and represent the most recent work; they were not used in the production of this paper as, at the time, the third was not published, and the first and second came to my notice when the work was already completed. But, taking them into consideration before going to press, I am of the opinion that it is neither necessary nor wise to alter any of the specific determinations. When there is more general agreement as to the characters of species and mutations further differentiation may perhaps seem to be justified, but, in my opinion, that time has not yet arrived:-

- 1923. C. DEPÉRET & L. MAYET. 'Monographie des Eléphants Pliocènes de l'Europe & de l'Afrique du Nord' Ann. Univ. Lyon—Sciences, n. s. fasc. 42, pp. 89 et seqq.

 Do. do. 'Origine & Evolution des Elephants' La Nature, August.
- 1924. C. FORSTER COOPER. 'On the Remains of Extinct Proboscidea in the Museums of Geology & Zoology in the University of Cambridge' Proc. Camb. Phil. Soc. (Biology) vol. i, pp. 108 et seqq.

EXPLANATION OF PLATES III-VI.

PLATE III.

[All figures are half of the natural size.]

- Fig. 1. Elephas antiquus, archaic (L.H. 2): crown of 1. 3rd (?) lower true molar. Long Handborough.
 - 2. Elephas antiquus, cf. trogontherii (L.H. 4): crown. 3rd lower true
 - molar. Long Handborough.
 3. Elephas trogontherii Pohlig (L.H. 5): crown. 2nd (?) upper true molar, Long Handborough.

PLATE IV.

Fig. 1. Elephas antiquus, archaic (L.H. 2): side view, a third of the natural size. 3rd (?) lower true molar. Long Handborough.

- Fig. 2. Elephas antiquus, cf. trogontherii (L.H. 4): side view, a third of the natural size. 3rd lower true molar. Long Handborough.
 - 3. Elephas antiquus (W.1): crown, half of the natural size. 3rd upper true molar. Wolvercote.
 - 4. Elephas antiquus: crown, half of the natural size. MM3 or MM1, lower. Hurley Bottom. Falconer, Pal. Mem. vol. ii, p. 179.

PLATE V.

- Fig. 1, Elephas antiquus: side view, a third of the natural size. MM3 or M1,
 - lower. Hurley Bottom. Falconer, 'Pal. Mem.' vol. ii, p. 179.

 2. Elephas antiquus: crown, half of the natural size. 3rd milk-molar. upper. Hurley Bottom. Falconer, 'Pal. Mem.' vol. ii, p. 177.
 - 3. Elephas antiquus: side view, a third of the natural size. 3rd milkmolar, upper. Hurley Bottom. Falconer, 'Pal. Mem.' vol. ii, p. 177.
 - 4. Elephas antiquus: lower jaw, a third of the natural size. Wytham. Leith Adams, Monogr. Palæont. Soc. 1877-81, p. 21.

PLATE VI.

- Fig. 1. Elephas primigenius (S. 44): crown, a third of the natural size. 3rd true molar, lower. Langford Lane, near Oxford.
 - 2. The same: side view, a third of the natural size.
 - 3. Elephas primigenius (C.1): crown, a third of the natural size. 3rd true molar, upper. Leith Adams Monogr. Palæont. Soc. 1877-81. p. 115. 'Bed of Cherwell.'
 - 4. The same: side view, a third of the natural size.
 - 5. Elephas antiquus (S. 30): mandible, a third of the natural size. Old Angel, Oxford, 1877.
 - 6. Elephas primigenius (S. 29): crown, 2nd upper milk-molar, Leith Adams, Monogr. Palæont. Soc. 1877-81, p. 91, half of the natural size. Near Oxford, Iffley Drainage, 1874.
 - 7. The same : side view, half of the natural size.

Discussion.

The President (Dr. J. W. Evans) commented on the difficulty of determining the succession and correlation of the British Pleistocene deposits.

Mr. S. HAZZLEDINE WARREN congratulated the Author upon an important piece of detailed work, in which the relation between the stratigraphy and the paleontology of the River-drift terraces was clearly brought out. The investigation would throw much light upon the general correlation of the Pleistocene deposits, which were so extremely complicated and difficult to classify in detail. It was particularly interesting to have the evidence in the 20-foot Terrace of a cold stage with Elephas primigenius, followed by warmer conditions with E. antiquus. The speaker believed that the Ponder's End horizon was slightly earlier than the buried channel of the Thames Valley, but would probably be later than the cold stage of the 20-foot Terrace.

The AUTHOR thanked the speakers for their remarks, and expressed his gratitude to Dr. C. W. Andrews for his unfailing interest in the work, and for much valuable advice, also for verifying the determination of the teeth from the Handborough Terrace and the Wolvercote Channel.

3. A New Catopterid Fish from the Keuper of Nottingham. By Henry Hurd Swinnerton, D.Sc., F.G.S., Professor of Geology in University College, Nottingham. (Read June 4th, 1924.)

[PLATES VII & VIII.]

The material for the investigation which is the subject of this paper was found in the year 1912 at Woodthorpe, an estate which lies just beyond the borough boundary of the city of Nottingham. During the development of this estate for building purposes several deep sewer-trenches were made: these passed through the base of the Keuper Waterstones, which in this district is clearly defined by the presence of a layer of conglomerate usually not more than 6 inches thick. Above this is a compact, fine-grained, yellow sandstone about 2 feet thick, which splits easily along certain planes determined by the presence of thin films of clay. The surfaces of the slabs thus formed were either irregularly undulating, or quite flat.

In the case of the slabs with undulating surfaces numerous well-preserved remains of *Semionotus* were found embedded side by side in the rock, at a depth of from one-eighth to a quarter of an inch below the surface. This mode of occurrence was strongly suggestive of the habit exhibited by some existing freshwater fishes. In dry seasons, when there is a danger of the water drying up, they bury themselves in shoals in the mud at the bottom of the canal or pool in which they live, and remain there until the water is renewed. For the particular fossil fishes under discussion

In the case of the slabs with flat surfaces the number of fishes was smaller; and each lay with the trunk, tail, and fins exposed, but with the head enclosed in a thick film of clay. In addition to Semionotus there also occurred a number of much smaller fishes belonging to the family Catopteridæ, which is of peculiar interest by reason of its systematic position between typical Palæozoic Palæoniscidæ and Mesozoic Ganoidei. The specimens were sufficiently well preserved to supply further details concerning the osteology of this comparatively little-known family. In all there were ten specimens belonging to one species, which proved on examination to belong to a new genus: this it is proposed to call Woodthorpea wilsoni.

[Note.—Up to the time of reading this paper I hesitated to go further than the institution of a new species. In consequence, however, of the discussion which followed I became convinced that

¹ H. H. Swinnerton, 'The Keuper Basement-Beds near Nottingham' Proc. Geol. Assoc. vol. xxix (1918) p. 18.

it was desirable to establish a new generic, as well as a new specific, name. The text of this paper has been altered accordingly. The generic name is derived from Woodthorpe, where the material was found. The specific name is in honour of the late Mr. Edward Wilson, who was the first to find fossil fishes in the Trias of the Nottingham district.

SYSTEMATIC DESCRIPTION.

Genus WOODTHORPEA nov.

Body fusiform, clad with ganoid scales. Head, including operculum, small, about a fifth of the length of the body. Suspensorium vertical, or but slightly inclined. Eye of moderate size, and situated just in front of the middle of the head. Surmaxilla and interoperculum present in the face. Small infraclavicle present in the shoulder-girdle. Fulcra present in all fins, few in number, and making only a small angle with the margin of the fin. Caudal pedicle deep; caudal fin hemiheterocercal, with a slender extension of the axis into the upper lobe.

Type-species, Woodthorpea wilsoni, from the basement-bed of

the Keuper Waterstones of Nottingham.

WOODTHORPEA WILSONI Sp. nov.

A small species about 46 mm. long. Length of head about the same as the maximum depth of the body, which is 11 mm. deep. Maximum depth of body not quite twice that of the caudal pedicle. Paired fins small. Pectoral, pelvic, ventral, and caudal fins equidistantly placed. Dorsal fin of moderate size, and situated in front of the ventral. Scales relatively large, those on the trunk with slightly rounded free margin, those on the venter elongated, those on the caudal pedicle rhombic. Ten to thirteen scales in a vertical row, eighteen rows between the head and the dorsal fin; ridge-scales of the same region sharply spinous.

Of the ten specimens which have been examined for the purposes of this paper No. 4 is the most perfect, and may be taken as the type. Features not shown by it are seen to the best advantage in one or other of specimens 2, 3, 9. These are all in the Collections of the Geological Department of University College,

Nottingham.

Material.

All the specimens of *Woodthorpea* that were found had suffered loss of some portion of the body. As a rule, the head was the least affected, owing to the fact that it was buried in clay. On the other hand, the fins and tail were frequently much damaged. The main features of each specimen may be inferred from the accompanying table of measurements.

¹ Q. J. G. S. vol. xliii (1887) p. 539.

QUART. JOURN GEOL. SOC, VOL. LXXXI, PL. III.



J Hambidge Photo.

ZINCO COLLOTYPE CO., EDINBURGH.



QUART. JOURN GEOL. SOC, VOL. LXXXI,PL. IV



HJ Hambidge Photo.

ZINCO COLLOTYPE CO., EDINBURGH.





ELEPHAS ANTIQUUS



QUART JOURN. GEOL. SOC , VOL. LXXXI,PL. VI. HJ Hambidge Photo.

ELEPHAS PRIMIGENIUS and E. ANTIQUUS



General Description.

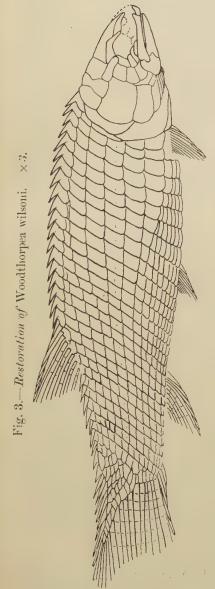
The body as a whole is fusiform in outline (text-figs. 1-3), having an average total length, from the tip of the snout to the caudal end of the trunk, of 46 mm. The maximum depth is situated just in front of the pelvic fin, and averages 11 mm. The head is relatively small, and occupies a fifth of the length of the body. The

OODTHORPEA WILSONI.	7 8 9 10 Average.,	44.5 45 47 49 46	bies a 01 11 11 01 6	27 26 27 29 28	31 29 31 — 31	24 - 23 26 23	04 04 05 05 05 05 05 05 05 05 05 05 05 05 05	1.5 4.8 6 6 8 c.7	10 10 11 11 11 0	5.3 5.5 6 6.5 5.9
OF W	9		10	27	1			00	133	
ENS	20	1	6	26	1	23.6		œ	11	1
CIM	4	48	9.6	59	31	25.1	1	6	11.5 11	1
SPE	က	48	10.5	29	33	25	42	9.2	12	9
Ten	67	1	1.0	1	31	25		00	10.5	1
S OF	-	43	10	29	32		41	œ	11	1
MAIN MEASUREMENTS IN MILLIMETRES OF TEN SPECIMENS OF WOODTHORPEA WILSONI.	Number of Specimen	Length. Tip of snout to the base of the tail-fin.	Do. Do. do. the edge of the oper-	Do. Do. do. the dorsal fin	Do. Do. do. the ventral fin	Do. do. the pelvic fin	Do. Do. do. the caudal fin (ventral) 41	Depth at the posterior border of the operculum.	Depth at the auterior border of the pelvic fin	Depth of caudal pedicle

caudal pedicle is deep; but, within the region of the tail-fin, it contracts rapidly in a typically hemi-heterocercal manner. It differs, however, from normal tails of this type which have been described, in having a highly attenuated extension (Pl. VIII, fig. 1) that reaches almost to the tip of the upper lobe of the fin. This is an interesting relic of the more primitive heterocercal condition.

Fig. 1.—Type-specimen (No. 4) of Woodthorpea wilsoni. $\times 3$.





The trunk and tail are covered with rhombic ganoid scales. Anteriorly these overlap one another extensively. and tend to have rounded free margins. Along the mid-dorsal line, from the head to the dorsal fin there is a series of twenty ridgescales, each extended upwards into a stout sharp spine. Towards the lower surface of the trunk the scales become progressively shallower, and consequently more elongate in form. The scales are arranged in rows inclined obliquely backwards downwards. The number of such rows between the shoulder-girdle and the anterior upper margin of the tail-fin is thirty, and the number of scales in each is from twelve to fourteen. On the upturned portion of the caudal axis (Pl. VIII, fig. 1) the slope of the scalerows is reversed, a feature which is characteristic of the corresponding region of the Palæoniscidæ. The attenuated hinder half of the axis is covered by a single row of

The median fins include a moderately large dorsal, a small ventral, and a large caudal. The anterior border of the dorsal (text-figs. 1–3) is placed almost exactly midway between the head and the tip of the caudal axis. The ventral fin lies a little behind the hinder border of the dorsal. The caudal fin

is apparently not forked; but in no case was it sufficiently well preserved to provide data for an accurate description of its outline.

Of the paired fins the pectorals are comparatively small, and arise low down upon the trunk. The pelvic fins are removed from them by nearly a third of the total length of the trunk. All the fins are provided with fulcra.

The head.—The head is deepest at its hinder end. Thenceforward it diminishes rapidly towards the snout, which appears to have been blunt, and to have projected slightly beyond the gape. The orbit is moderately large, and situated with its hinder margin

in the middle of the length of the head.

The facial and opercular regions are made up of numerous delicate bones. Those of the opposite sides are crushed one against the other, in such a way as to indicate the absence of an ossified internal skeleton between them. The bones of the cranial roof and jaws, on the other hand, are stout, and, owing to their superior strength, have been turned over sideways (Pl. VII, fig. 1; & text-fig. 1, p. 90) instead of being crushed laterally. In consequence of this the face is obscured in some specimens, in others (Pl. VII, fig. 2; & text-fig. 2, p. 90) it is extensively exposed, according to the way in which those parts have been turned over.

The cranial roof.—In several specimens (Pl. VII, fig. 1) the roof of the crushed cranium happens to face outwards upon the surface of the slab, thus making a study of the elements possible. All bones are covered with enamel, and their surfaces are more or

less ornamented, but not sculptured.

Three pairs of bones—frontals, parietals, and supratemporals—abut one against the other along the median line. The frontals are the largest, and occupy nearly a half of the cranial roof. Each is narrow in front and broad behind. The parietals are as broad as the hinder margin of the frontals, and are quadrangular in outline. The supratemporals are slightly broader than the parietals, but less than half their length. Intimately associated with the hinder border of the supratemporals are the post-temporals.

Three pairs of long narrow bones flank the cranial roof. The squamosal lies along the outer margin of the parietals. The large supraorbitals flank the hinder portions of the frontals, and form the upper margin of the orbits. The nasals or anterior frontals lie alongside the narrow front portion of the frontals, and project some distance in front of these. In the type-specimen the anterior portion of this bone appears to be separate. No median ethmoid

was found.

The facial region.—The bones of the facial region (textfig. 3, p. 91; & Pl. VII, figs. 1-2) are arranged more or less concentrically in relation to the orbit. The upper boundary of the orbit is determined by the supraorbital. The bones in front appear to have been very delicate, and consequently are not sufficiently well preserved to allow of even an approximate delimitation of their boundaries. Indications point to the existence of two or three bones in front of the orbit. Behind and below the orbit was a series of four, making up a total of six or seven circumorbitals. Behind these lie three much larger postorbitals, extending from the squamosal above to the upper margin of the lower jaw. The two uppermost trend obliquely downwards and backwards; the others slope forwards towards the jaw.

The preoperculum extends from the squamosal to the angle of the lower jaw; but its upper portion is usually overlapped, and hidden from view, by the posterior margin of the upper two postorbitals. On its exposed surface it is triangular in form, with its

lower anterior angle truncated against the lower jaw.

The gill-cover is large, and is supported by a series of bones of which the biggest is the operculum. This has an approximately rhombic outline, with the anterior and hinder margins sloping obliquely downwards and backwards. The suboperculum is of the same length as the operculum, but is not so deep. Between the anterior end of the suboperculum and the angle of the lower jaw lies a small interoperculum. Below the suboperculum comes a series of about eleven branchiostegal rays, each of which is flattened and elongated in form. Those in front are reduced in size. No gular plates have been found.

The mouth region.—The gape (text-fig. 3, p. 91 & Pl. VIII, figs. 1 & 2) is wide, and extends from near the anterior extremity of the head to the posterior border of the eye. The upper margin of the mouth is defined by a pair of small premaxillæ in front and large maxillæ behind. The former project slightly beyond the tip of the lower jaw, and exhibit traces of ascending processes. The latter are slightly expanded and plate-like behind, and show a large notch in the posterior border. Anteriorly they are stouter and more rod-like, and have an articulation with the ethmoidal region in front. The lower margin of each maxilla is concave, and its upper margin convex. Overlying the hinder half of each maxilla is an elongated splint-like surmaxilla.

The lower jaw, as seen from the outside, consists of a dentary bone and an angular. The former is shallow in its anterior half, which deepens, however, gradually from its tip to the middle of the jaw. At this point the upper margin of the bone rises rapidly to form the front portion of the coronoid region. The posterior margin is excavated by a deep notch. The angular flanks the outside angle of the hinder portion of the jaw, and fits into the notched border of the dentary. The inner surface of the jaw has not been

seen.

Traces of teeth have been noted on the margin of the maxilla. They are apparently of small size and sharp conical outline. The difficulty of dissecting structures so minute from the sandy matrix has hitherto made it impossible to gain very definite information in regard to these structures.

The shoulder-girdle.—Portions of this have been seen (text-figs. 2-3, pp. 90-91; & Pl. VII, fig. 2) in almost all specimens. Wherever its bones are exposed, they have enamelled

surfaces with indications of sculpturing.

The clavicle is a large arcuate bone having an upper ascending portion and a lower forwardly projecting one. The upper process is a broad flat plate flanking the posterior margin of the sub-operculum. The lower process abuts against the posterior margin of the hindmost branchiostegal ray, and then bends inwards on to the under surface of the head, where it is hidden from view by the branchiostegal rays. When these are removed, the clavicle is found at its anterior end to be drawn out into a point which apparently meets its fellow of the opposite side. The anterior margin of the clavicle is grooved, and passes from view under the margin of the gill-cover.

No undoubted traces of an anteriorly placed interclavicle, such as that which occurs in the Palæoniscidæ, have been found. There is present, however, a long narrow enamelled bone, which extends forwards along the lower and inner margin of the clavicle from the vicinity of the pectoral fin. Its position suggests that it may be an interclavicle, which has been pushed out of place by the forward and inward extension of the clavicle. It appears to be homologous with a similarly placed bone, which occurs in some

species of Dictyopyge 1 and is called the infractavicle.

A postclavicle lies along the hinder border of the ascending ramus of the clavicle, above the insertion of the pectoral fin.

The supraclavicle lies with its lower end between the upper extremity of the clavicle and the posterior margin of the operculum. Its upper end abuts against the lower posterior corner of the post-temporal.

The post-temporal is nearly as large as the supratemporal, and

meets its fellow in the middle dorsal line.

Search has been made for both the scapula and the coracoid; but hitherto only insignificant traces have been found, a fact which may be due to lack of ossification.

Median fins.—Faint traces of a few endodermal rays were found (Pl. VIII, fig. 2) for the dorsal fin, in the type-specimen. Evidently, they were but superficially ossified. The close approximation of the upper end in some cases to the dermal ray points to an advanced stage in evolution, comparable with that of the Mesozoic Ganoids and the Teleosts.

The ectodermal rays are frequently well preserved, and those that are not especially modified are made up of quadrangular enamel-clad segments (Pl. VIII, figs. 1 & 2). These tend to become broader distally, where they appear to be more delicately constituted and less frequently preserved. The anterior border of each

¹ A. S. Woodward, Fossil Fishes of the Hawkesbury Series at Gosford Mem. Geol. Surv. N.S.W. Palæont. No. 4 (1890) p. 19 & pl. iv, fig. 7.

fin is strengthened by several overlapping spiny rays. The first is short, and occupies only a fourth of the fin-margin. The others lengthen progressively, until the tip of the last lies at about the middle point of the fin-margin. Beyond this there is a small number of overlapping fin-fulcra which make a low angle with the margin. The first and largest of these extends forwards from beneath the distal end of the last spiny ray. The remainder decrease in size towards the extremity of the fin. The outlines of the free portions of the fins have not been determined.

The dorsal fin is best preserved in specimens 3, 4, & 11. It is 7 mm. long, and its anterior border is strengthened by three spiny rays and four fin-fulcra. Seven ordinary rays support the

remainder of the fin.

The ventral fin is best preserved in specimen 8, and less well preserved in specimens 4 & 2. Its anterior margin is but slightly shorter than that of the dorsal, while its base of attachment is three-quarters of the length of that fin. The margin is strengthened by three spiny rays and at least three fin-fulera;

seven ordinary rays support the rest of the fin.

The caudal fin is best preserved in specimen 9 (Pl. VIII, fig. 1) and moderately well preserved in specimens 3, 8, & 10. Its dorsal border is made up of ten or eleven elements. The first six of these are broad-based spiny rays, each corresponding in its attachment with the edge of the topmost scale of a row that slopes obliquely downwards and forwards across the pedicular lobe. The seventh ray is related to an odd scale. The remaining elements become progressively more like ordinary fin-fulcra, and have no definite relationship to the scales. The ventral border of the fin has four overlapping spiny rays, making up half of its length, and only two fin-fulcra. As in the other unpaired fins, the next ray appears to end in a point which does not reach the tip of the fin. Fifteen ordinary rays, including the pointed one just mentioned, make up the remainder of the fin. These rays are broader than those of the other fins, and the presence of clearly marked quadrangular segments gives to the tail that reticulate appearance which is so characteristic of the allied genus Dictyopyge. Generally, there is one ray for each scale that makes up the margin of the caudal pedicle.

Paired fins.—The elements which make up the anterior borders of these are similar to those in the unpaired fins. The ordinary rays, though segmented, do not appear to consist of the same quadrangular parts. The lines of attachment of the fins to the body are placed horizontally, as in primitive bony fishes.

The pectoral fin is moderately well preserved in specimens 3, 6, & 8. This fin is 5 mm. long. It has three overlapping spiny

rays, at least two fin-fulera, and nine ordinary rays.

The pelvic fins are well preserved in specimen 3, and less well preserved in specimens 2 & 10. This fin is 3.5 mm. long. Its border is supported by three spiny rays, and at least one finfulcrum. Six ordinary rays make up the remainder of the fin.

Discussion of the Affinities of Woodthorpea wilsoni.

The fossil fish described above is a typical Actinopterygian. Assuming that the bone which has been called the 'infraclaviele' is homologous with that called the 'interclaviele', then Woodthorpea belongs technically to the Chondrostei. This, however, is the only diagnostic character which it possesses in common with the typical Chondrostei. It must, therefore, be placed with the Catopteride, a family of non-typical Chondrosteans. Like other members of this family, it shows modification approximating to the Protospondylian type, especially in the abbreviate or hemiheterocercal condition of its tail. In the presence of an attenuated extension of the upturned axis of the tail, it exhibits a slightly less-advanced condition than that hitherto recorded for other members of this family.

Only two genera have been recorded for the family Catopteridæ ¹: namely, Catopterus and Dictyopyge. These are distinguished one from the other taxonomically, by the fact that in the former the dorsal fin is situated behind the ventral, while in the latter it is not behind. On the basis of this distinction, Woodthorpea is

placed near the genus Dictyopyge.

An examination of the published figures 2 of species of Dictuopuge, and of such specimens as are preserved in the collections of the British Museum (Natural History) and of the Geological Survey, shows that they fall into at least two categories. In some, which may be spoken of as Group A, the head is large, and occupies about a quarter of the length of the body; the eye is far forward, the gape is very long, and its suspensorium has a very marked backward and downward slope. In these species the head, as a whole, presents a striking likeness to that of the Palæoniscidæ. wherefore their affinity with this family is obviously quite close. To this group belong the following species: -D. illustrans, D. robusta, D. symmetrica, and D. draperi. In other species: namely, D. macrura, D. catoptera, D. socialis, and D. superstes. which may be defined collectively as Group B, Palæoniscid affinity is not so evident. The head is small, its length being contained 41 to 5 times in the length of the body. The orbit is not far forward, but is situated over the hinder portion of the gape, which in turn is smaller than in members of Group A. Moreover, the suspensorium is inclined but slightly backwards, or it may be vertical.

The affinities of Woodthorpea are with Group B, and not

¹ Brit. Mus. Catal. of Fossil Fishes, pt. iii (1895) p. 1.

² Sir P. Egerton, Q. J. G. S. vol. iii (1847) p. 276 & pl. viii, pl. ix, fig. 1; J. Strüver, Zeitschr. Deutsch. Geol. Gesellsch. vol. xvi (1864) p. 322 & pl. xiii, fig. 2; Sir P. Egerton, Q. J. G. S. vol. xiv (1858) p. 165 & pl. xi, figs. 1-4; W. Deecke, Palæontographica. vol. xxxv (1889) p. 107 & pl. vi, fig. 11; A. S. Woodward, Mem. Geol. Şurv. N.S.W. Palæont. No. 4 (1890) pl. iii, figs. 4-5 & pl. iv, figs. 5-9; and id., Ann. Mag. Nat. Hist. ser. 6, vol. xii (1893) p. 393 & pl. xvii, fig. 1.

with Group A. Within Group B it is most closely allied to Dictyopyge superstes. The type-specimen of this species, preserved in the British Museum (Natural History), has no head; but the detailed resemblance of the parts that are left to the corresponding portions of Woodthorpea is so great, that it is highly probable that D. superstes should be put with the new genus. These resemblances are manifested in the shape of the body; in the character, number, and size of the flank-scales; in the spinous ridge-scales; in the presence of shallow abdominal scales; in the condition of the fin-rays, which is such that they do not appear to be so thickly coated with enamel as do those of the other species: the fin-fulcra are few in number, have the same elongated form, and make the same small angle with the fin-margin. Owing to this condition of the fulera, the margins of the fins do not present that finelyserrated appearance that is seen in the majority of the Catopterid fishes. In them the fulcra are more numerous, deeply overlapping, and steeply inclined to the fin-margin.

Woodthorpea wilsoni differs from D. superstes in being a smaller though relatively stouter fish, in the more markedly spinous character of its ridge-scales, in the less direct superposition of the dorsal above the ventral fin, and in the smaller ventral fin (which has fewer rays and no vertically placed scales along its line of attachment). The pelvic fin of W. wilsoni is also placed farther back than in D. superstes.

The Catopteridæ have, for many years, been classified with the Palæoniscidæ in the Chondrostei. They were referred to this position by Sir Arthur Smith Woodward 2 as long ago as 1895, because of the presence of an infraclavicle in the shoulder-girdle and the backward rotation of the hyomandibular suspensorium. He recognized, however, that they were not typical Chondrosteans, but were much more generalized than other members of this group. On the other hand, he states that 'the Catopteridæ of the Trias incline towards a higher type of fish than the Chondrostei, to which they technically belong.' This he considered was indicated by the facts that the 'tail is only hemiheterocercal,' and 'the single series of supports in the dorsal and anal fins almost equal in number the apposed dermal rays.' E. S. Goodrich 3 in 1909 goes further, and expresses the opinion that 'the Catopteridæ undoubtedly approach the Holostei, with which they should possibly be classified.

The further light thrown upon the structure of this family by the remains of Woodthorpea confirms these conclusions, and emphasizes yet more strongly its border-line character: for, while some of its members have marked Paleoniscid affinities, the new genus may also be described as having crossed the line. In the

¹ Q. J. G. S. vol. xiv (1858) p. 165.

Brit. Mus. Catal. Foss. Fishes, pt. iii, p. vii.
 'Treatise of Zoology [ed. by E. R. Lankester], pt. ix, Vertebrata Craniata' 1909, p. 313.

Q. J. G. S. No. 321.

attenuated extension of the caudal axis and the presence of a small infractavicle are revealed traces, but only traces, of affinity with the lower types. Nevertheless, in each case, the departure from the Palæoniscid condition is in the direction of a higher race. On the other hand, the slightness of the expansion of the hinder end of the maxilla, the presence of a surmaxilla and of an interoperculum, and the small upward extension of the preoperculum

are all essentially Protospondylian characters. Among the Protospondyli there are only two families: namely. the Semionotide and the Eugnathide-which, by reason of their form, structure, and mode of occurrence, suggest comparison with Woodthorpea. This genus is differentiated from the Semionotida by the large size of its mouth and by the vertical or backwardly inclined mandibular suspensorium, both of which characters it has in common with the Eugnathide. In the extent of the preorbital region of the head, the notching of the posterior end of the maxilla, the form, number, and arrangement of the cheek-plates, and the characters of the cranial roofing-bones, its resemblance to this family is still further emphasized. Indeed, if it were not for the presence of an infractavicle in its shoulder-girdle, Woodthorpea could not be separated from the Eugnathidae-it here represents this bone just on the verge of disappearance. Only one small step further in reduction is required to justify the transference of this genus to the Eugnathida, as the lowliest and most primitive member of that family.

EXPLANATION OF PLATES VII & VIII.

All the specimens figured are in the collections of the Geological Department of University College, Nottingham.]

PLATE VII.

Fig. 1. Woodthorpea wilsoni, gen. et sp. nov. Lateral view of the head of specimen No. 4. × 5. 2. W. wilsoni. Lateral view of the head of specimen No. 2. × 5.

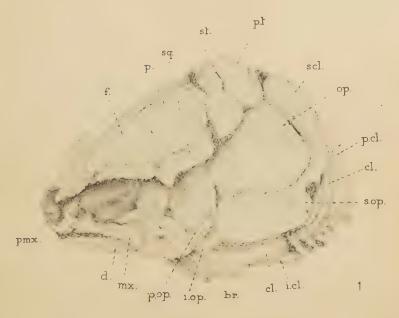
PLATE VIII.

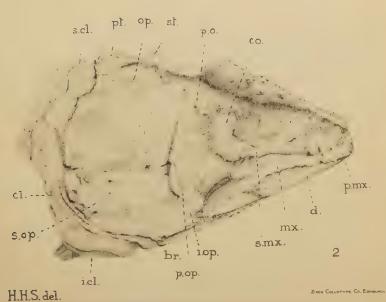
Fig. 1. W. wilsoni. Tail of specimen No. 9. × 5.

2. W. wilsoni. Dorsal fin of specimen No. 4. Over the lightly shaded portion of the scaled area the scales of the left side have been removed, and the inner surfaces of those of the right side are exposed. \times 5.

Index to lettering.

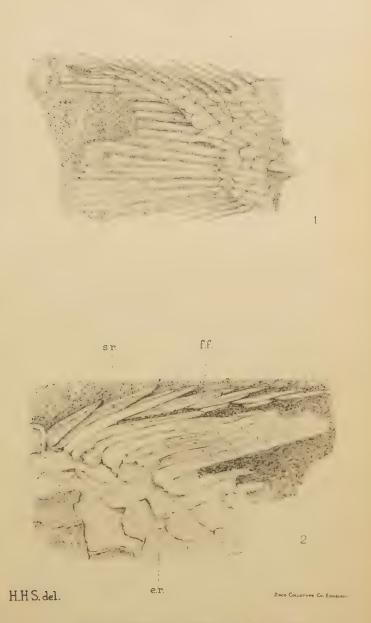
Br. branchiostegal rays; cl. clavicle; co. circumorbital; d. dentary; e.r. endodermal rays; f. frontal; f.f. fin-fulera; i.el. infraelaviele; i.op. interoperculum; mx, maxilla; op. operculum; p. parietal: p.cl. postclavicle; p.mx. premaxilla; p.op. preoperculum; p.t. post-temporal; s.cl. supraclavicle; smx. surmaxilla; s.op. suboperculum; sq. squamosal; s.r. spiny ray; st. supratemporal.





WOODTHORPEA WILSONI, gen. et sp. nov.





WOODTHORPEA WILSONI, gen. et sp. nov.



DISCUSSION.

Sir Arthur Smith Woodward welcomed the paper as an important contribution to our knowledge of the early Mesozoic fishes. The new species seemed to show that the so-called *Dictyopyye superstes*, from the Keuper of Warwickshire, did not belong to the genus to which it had been referred. He recognized nothing Palæoniscoid in the new fish, unless the presence of infraclavicles could be substantiated.

Prof. D. M. S. Watson expressed the hope, that, as the characters of the type-species of the genus *Dictyopyge* are practically unknown, the Author would found a new genus for the fish of the osteology of which he had given so good a description. He demurred to the inclusion of the new form in the Catopteride, and suggested that it might appropriately be included in the Eugnathidæ.

The President (Dr. J. W. Evans) enquired whether he was right in supposing that the deposit in which the fishes were found was of freshwater origin. The mode of occurrence was similar to that of the aggregates of fish-remains in the John o' Groats Beds. The earlier Ganoids apparently all lived in fresh water, although

some of the later forms were doubtless marine.

The AUTHOR replied that he had hesitated to suggest the establishment of a fresh genus for the fossil fish which he had just described. In view, however, of the remarks which had been made, he thought that it would be advisable to introduce a new generic name into the published paper. In reply to the President's question, he suggested that the habits of the fishes found in the Waterstones, together with the alternation of fish-bearing with sun-cracked layers, and the absence of salt pseudomorphs, indicated, although they did not prove, freshwater conditions.

4. A Preliminary Survey of Metamorphic Zones in the Southern Highlands of Scotland. By Cecil Edgar Tilley, Ph.D., B.Sc., F.G.S. (Read June 4th, 1924.)

[PLATE IX-MAP.]

CONTENTS.

	CONTENTS.			
I.	Introduction	100		
II.	Metamorphic Zones of the Southern Highlands of Scotland.	101		
	(a) Zone of Chlorite.			
	(b) Zone of Biotite.			
	(c) Zone of Almandine.			
	(d) Inclination of the Zonal Surfaces in Perthshire.	100		
III.	Concluding Remarks	106		
IV.	Bibliography	109		

I. INTRODUCTION.

Thirty-one years ago, Mr. George Barrow (1) presented to this Society his classic account of the intrusion phenomena of a group of 'Older Granites', in the Forfarshire area of the South-Eastern Highlands. That paper is distinguished by reason of the clear enunciation of the two outstanding conclusions to which the author was led. In the one was illustrated for the first time the effect of crustal stresses on the differentiation-course of igneous magma, a process which plays so important a part in present-day theories of petrogenesis; in the other, also for the first time, was indicated the subdivision of a group of highly-metamorphosed sediments into metamorphic zones characterized by the presence of critical index-minerals. So far as I am aware, his paper represents the first attempt in petrological literature to bring precision to the study of regional metamorphism, by laying upon a map zonal lines indicative of varying grades of metamorphism.

It is chiefly upon this aspect of Barrow's work that I shall

dwell in the matter now set forth.

Nineteen years later (2) he extended the area of his zonal metamorphic map, at the same time increasing the number of zones. The map presented to the Geologists' Association thus covers the ground included in the quarter-inch sheet (No. 12) of the Geological Survey map of Scotland, extending to the Highland Border from Stonehaven to Dunkeld. In the meantime, other Scottish investigators by extended surveys of Perthshire and Argyllshire were bringing to light new data on the metamorphism of these regions. Chief among these were C. T. Clough, J. B. Hill, and E. H. Cunningham-Craig, who, by their study respectively of the Cowal area, the Loch Awe region, and Western Perthshire,

 $^{^1}$ Numerals in parentheses refer to the Bibliography, \S IV, p. 109.

have made fundamental contributions to the knowledge of the

metamorphism of the Southern Highlands.

In later years the intensive investigation of metamorphism in the Southern Highland region has been largely associated with the name of E. B. Bailey, whose latest researches were "published as recently as July 1923. As Mr. Bailey's paper (4) presents in easily accessible form the most important literature on the subject of the metamorphism of this region, I have no need here to refer specifically to those publications.

The province of the South-Western Highlands has been mapped by Bailey into zones which have other indices than those adopted by Barrow; these zones have from their nature much less precision, and I cannot regard the validity of one of them as otherwise than highly questionable. The metamorphic distribution as thus mapped out is considered especially in relation to a structural interpretation of the area advanced by Mr. Bailey in 1922 (3). On the origin of the albite-schists, which form so prominent a group in Cowal and the region of Loch Lomond, his views coincide with those of Cunningham-Craig, and he emphasizes this agreement by contrasting an albitic with a garnetiferous metamorphism. Finally, treating garnet and albite in the sediments as antipathetic minerals, Bailey discusses the time-relations of the development of these two minerals.

II. METAMORPHIC ZONES OF THE SOUTHERN HIGHLANDS OF SCOTLAND.

The widespread distribution of sediments of argillaceous type in the Dalradian System of the Southern Highlands at once marks out, apart from other considerations, these rocks as a suitable group in which to study successive and progressive mineral changes. Such are the rocks which Barrow has used in his zonal mapping of Forfarshire and Kincardineshire. In the summer of 1922, I began an examination of the country lying west and south-west of Dunkeld, mainly in the area included in Sheet 47 of the Geological Survey Map, with the purpose of identifying and continuing the zones which were carried as far west as the vicinity of Dunkeld itself. Owing to the fact that rocks of higher grades of metamorphism, such as those carrying staurolite and kyanite, are seen to recede continuously farther from the Highland Border as we proceed south-westwards, none of these zones was encountered in the ground that I have examined. The north-western limit of the ground mapped in Perthshire is, therefore, located within the outcrop of the garnet-zone. As will appear from the data which follow, the work bears out and confirms the very remarkable pioneer investigations of Barrow in the South-Eastern Highlands. The area over which zonal lines have been drawn in this manner includes the Highland sediments extending from the Highland Border to the Ben Lui Schists, structurally overlying the Loch Tay Limestone, south-westwards from Dunkeld, to the western shore of lower Loch Fyne (Argyll). The map which is now produced connects directly with the area already mapped in Eastern Perthshire, the results of which were published by Mr. Barrow in 1912.

At the present stage of the investigation, I do not propose to

deal in detail with the metamorphism of this tract.

This paper is intended merely to illustrate the appended zonal map (Pl. IX). The nature of the different zones is, therefore, only briefly described; and I have concluded the account with a short statement as to the influence of these results on the knowledge of the time-relation of metamorphism in the history of the sediments, and their bearing on the current theories of Dalradian metamorphism.

(a) Zone of Chlorite.

In place of Mr. Barrow's two zones—(a) zone of clastic mica and (b) zone of digested clastic mica, the former of which is indicated on his map as extending from the River Ericht to the vicinity of Dunkeld—I have substituted throughout the zone of chlorite. In the first place, chlorite is a typical mineral of the lowest zone, and generally decreases in amount as successive higher zones are entered, being utilized in the synthesis of higher indexminerals. On the other hand, white mica persists throughout, and is often very abundant in the higher zones. I have not been able to establish in the present preliminary investigation any subdivision of this zone on a sufficiently satisfactory basis to insert further zonal lines. The argillaceous rocks close to the Highland Border, along the whole of the area from Dunkeld to Cowal, are true micaceous and chloritic slates; and examination of numerous types provides evidence that, in general, the white mica and chlorite have recrystallized with a parallel arrangement.

This is not to deny that elastic mica and elastic chlorite are unknown along the Highland Border tract, but simply that rearrangement has so frequently taken place that no zonal lines

drawn on that basis are readily determinable.

The zone of chlorite, as now used, therefore covers the tract of country extending from the Highland Border to the first points of entry of brown biotite in pelitic or psammopelitic sediment. The rock-type of its north-western border is a quartz-muscovite-chlorite-schist, usually of much coarser grain than the corresponding pelite of the Highland Border. Whatever be the case for this rock-type, it seems clear from a study of other sedimentary types, such as the Green Beds, that this zone will be subdivisible when the progressive metamorphism of those sediments is better known. The main difficulty will arise as a consequence of the more restricted distribution of these rock-types throughout the chlorite zone.

(b) Zone of Biotite.

The zone of chlorite extending from the Highland Border to the line representing the first point of entry of biotite has a width across its outcrop, least in the north-eastern area in the vicinity of Dunkeld, and ever greater towards the south-west, so that the biotite isograd becomes farther removed from the Border.

The widening of the outcrop of the chlorite zone is, however, not of a regular and continuous character, as may be seen by

inspection of the zonal map (Pl. IX).

I have not found it possible to insert the southern limit of biotite from simple examination in the field, and microscopic examination of thin sections or of powdered rock is necessary.

The limit of the biotite zone as thus defined is subject to less accurate determination than is the case for almandine which follows, and its determination is often beset with difficulties. The prime difficulty, I believe, arises as a result of the ready destruction of biotite, either by weathering or by retrogressive metannorphism. The resulting chlorite is not always readily distinguished, and in many cases cannot be separated from the true 'progressive' chlorite. Frequently, of course, reliet biotite surrounded by secondary chlorite may be recognized; and, further, the presence of abundant rutile developed as a sagenitic web in chlorite may be used with advantage as a safe indicator of original biotite. I have no doubt that some of the irregularities in the course of the biotite-line are due to difficulties of this nature.

It is of consequence to note here that the common brown biotite is now in question. A green to brownish-green pleochroic biotite arises at an earlier stage of metamorphism, and is frequently found some miles away to the south-east of the biotite isograd set down. It is, however, not usually a constituent of the normal pelitic rock, but is characteristic of certain varieties of Green Beds in which this green biotite and epidote are common associates. As analyses of rock-forming biotites show a wide range of composition, and the interrelation of their chemistry and optics is still to be worked out, these green biotites deserve special study, and it is not difficult to believe that the conditions of pressure and temperature for their synthesis are likewise subject to variation.

The most regular and sharply-defined portion of the biotite-line is that developed in Cowal, from a point on the Loch Fyne coast near Kilbride Bay, through the northern end of Bute to Colintraive, and then to a point close to Gairletter Point on Loch Long.

A number of the first points of entry of biotite were originally indicated by the detailed survey of C. T. Clough, and noted in the Cowal Geological Survey Memoir. On the western side of Loch Fyne, the biotite-line is evidently shifted by the fault which passes down the loch. I have traced the outcrop of the zone along this coast as far south as Rudha Leathan, and it probably extends for some distance farther south.

(c) Zone of Almandine.

The garnet isograd follows, on the whole, a much more uniform course throughout Perthshire and Argyll than the corresponding piotite-line. In this case the difficulties which beset the precise location of the latter line do not now enter: for, even when the rocks have been subject to powerful retrogressive metamorphism or weathering action, it is easy to trace the former presence of garnet by the habit and structure of its chlorite-pseudomorphs. For garnet in general, however, such processes are limited and local in their distribution throughout the area. The incoming of garnet as a constituent of the pelitic and psammopelitic sediment is so frequently defined, permitting the drawing of its south-eastern limit as a zonal line, and even, as I shall presently describe, of a determination of the inclination of its zonal surface over an area of marked topographic relief, that it is reasonable to conclude that the garnet owes its genesis to a reaction which is a dominant one over large areas. Into this question I shall not now enter, as it is hoped to deal with this aspect of the metamorphism in a later paper. From its first point of entry, garnet is almost without exception a constant constituent of normal pelitic sediment in the area mapped in Perthshire, and, indeed, as we know from Mr. Barrow's work, its field of stability extends throughout the higher zones.

In the map (Pl. IX) the north-western edge of the garnet zone is not defined for Perthshire. It is known, however, that this zone is succeeded in Central Perthshire by rocks which carry the index-minerals of higher zones, such as staurolite and kyanite. In Perthshire west of the Loch Tay Fault the garnet zone, too, is cut off by the lowly-metamorphosed sediments of the Ben Lawers ridge; while, in the vicinity of upper Loch Fyne, Ardrishaig Phyllites abut against the garnet zone after its passage through

the aureole of the Glen Fyne granite.

These areas are not, however, included in the present survey,

and are therefore beyond the scope of this paper.

In Southern Cowal, the outcrop of the north-western edge of the garnet zone approaches the south-eastern edge, and the zone continues in a narrow outcrop through Kilfinan to Auchaliek Bay. It is probable that the Southern Cowal outcrop has not quite the regularity and continuity shown on the map, but, owing to its narrowness and variation of pitch, is interrupted in places. Good sections of the garnet zone are to be seen along the coast from Auchalick Bay to Port Leathan. The garnets of this narrow tract in Cowal are always very small, and it is quite clear that only the edge of the zone is truncated. On the western side of lower Loch Fyne, the garnet zone is first encountered on the coast of the northern promontory of East Loch Tarbert, and the outcrop extends throughout the horizon of the Green Beds, Loch Tay Limestone, and Stonefield Schists. Its outcrop in Kintyre has not been further traced, but I have recorded it for some distance on the north side of the eastern end of West Loch Tarbert.

(d) Inclination of the Zonal Surfaces in Perthshire.

The course of the zones through Perthshire and Argyll having been briefly considered, it is pertinent to enquire whether any evidence is forthcoming as to the inclination of any of these interzonal boundaries, which I have elsewhere defined as isograd surfaces (5). Two methods for the solution of this problem offered themselves during the mapping of the zones:

- (a) By the nature of the displacement of the surface-outcrop of a zone along a dislocation-boundary.
- (b) By the trace of the zonal surface over an area of marked topographic relief.

An examination of a geological map of this area of the Southern Highlands shows that the Dalradian System has been cut up by a roughly parallel series of cross-faults, which displace the outcrop of any particular stratigraphical horizon, in some cases for considerable distances. The most important of these cross-faults are the Loch Tay, Luib, Inverherive, and Tyndrum dislocations.

On the appended map (Pl. IX) the displacement of the outcrop of the Loch Tay Limestone by these dislocations is clearly indicated. It will also be observed that the metamorphic zonal

outcrops are likewise displaced, and in the same direction.

Let us take the specific example of the Loch Tay Fault; the horizon of the Loch Tay Limestone is displaced at the surface from Loch Earn, on the west side, to the vicinity of Ardeonaig on Loch Tay. The garnet zone is similarly displaced, its southern edge running from the lower slopes of Meall a' Mhadaidh, near Lochearnhead, to Wester Tullich, about a mile north of Ardeonaig, on Loch Tay.

It is of interest to note at this point that I have found it necessary to shift the position of the Loch Tay Fault at Ardeonaig. The fault can be well seen in the Finglen Burn, close to its junction with the Ardeonaig Burn; the fault continues along the valley of the latter burn, almost three-quarters of a mile west of the course given to it on the Geological Survey map. I was first led to this correction in the outcrop of the fault by the sudden

change of metamorphism encountered in crossing this line.

The outcrops of limestone at Margbeg and Finglen (the latter not recorded on the Survey map) are therefore on the east side of the fault, and are to be correlated with the isolated syncline of limestone on the summit of Meall na Creige, $2\frac{1}{2}$ miles east-southeast of Ardeonaig. In the region between Loch Earn and Loch Tay, the limestones and Ben Lui Schists overlying them are almost horizontal. For the cross-faults of Luib, Inverherive, and Tyndrum there is a similar displacement of the metamorphic outcrops, the apparent movement being in the same direction as the stratigraphical horizons.

It is generally conceded by those investigators who have

studied the Dalradian of this Perthshire region that the structural succession is towards the north-west, the Ben Lui Schists overlying the Loch Tay Limestone, which in turn is superposed upon

the Pitlochry Schists.

If these cross-faults have a dominant vertical displacement, it follows that the inclination of the almandine zone for this area is at low angles to the north-west; but, lest any unbeliever should doubt the evidence supplied by these dislocations (for instance, if they be conceived essentially as wrench- or tear-faults), I shall pass to the second line of evidence proving the nature of the inclination of this zonal surface.

In the local coincidence of diversified topography, and a sharply defined outcrop of the southern edge of the garnet zone, the Braes of Balquhidder afford a very favourable opportunity of determining the inclination of the zonal surface. This may be demonstrated, for example, in the area between the Kirkton burn and Kendrum Glen, enclosing the mountain of Meall an t'Seal-

laidh (2793 feet).

In the Kirkton and Kendrum burns, the first entry of garnet is approximately at the 1250-foot contour; but, on the intervening hill, the outcrop at higher levels moves south-eastwards, for on the ridge itself the southernmost outcrop is not less than 600 yards south-east of the dolerite which cuts vertically the almost horizontally disposed Ben Lui Schists, the elevation being 2300 to 2400 feet. It follows from these determinations that the inclination of the zonal surface is at low angles to the north-west, these figures corresponding approximately to a dip of 15°. From these points, as for all other similarly situated positions in Perthshire, one may proceed for many miles over garnetiferous mica-schists until higher zones are entered, or, as in the case of the Loch Tay country, until the garnet zone ends abruptly against the sediments of the Ben Lawers ridge.

Consideration of the data embodied in the foregoing paragraphs leads me to state that the convergence of evidence points logically to the conclusion that for these regions of Perthshire the metamorphic zones are superposed with a low inclination to the northwest. They correspond in direction with the general structural

succession.

III. CONCLUDING REMARKS.

I cannot conclude this short account without reference to some at least of the implications of the results set down in the foregoing pages. So few of the metamorphic data of the Highland region are yet known with any semblance of precision that it is a precarious undertaking to draw conclusions from a preliminary investigation of so small an area; and, if I am emboldened to offer some suggestions at this stage, it is with the distinct understanding that what is now put forward may with further light be

otherwise explained. The data presented in the map make manifest that the Southern Highland region is divided up into zonal areas characterized by certain critical index-minerals, which give precision to the grade of metamorphism imposed on sediments enclosed within the zones. One further step seems clear: that successive zones in Perthshire recline at low angles to the north-west, being

superposed in an increasing grade of metamorphism.

The validity of the zones as metamorphic indices being unquestioned, and the recognition of grade of metamorphism as a resultant of the imposition of varying physical environment of temperature and pressure (static and stress), it reasonably follows that in Perthshire the metamorphic zones are inverted. The present structural sequence does not represent the disposition of the sediments when metamorphism was essentially effected. The mode of, or mechanism by which, such inversion has been brought about does not now concern us, and cannot be inferred from any evidence as yet supplied by this area. Proceeding still farther, it may be considered that the data probably provide general support for the view that has recently been gaining ground, that the north-western structural succession in Perthshire is an inverted stratigraphical sequence.

So far as I am able to judge, the evidence provided here is at least of the same order of reliability as that put forward by Mr. E. B. Bailey in his paper on the structure of the South-Western Highlands.

It is of no less importance to enquire how far the data here supplied can be considered in the light of current theories of Dalradian metamorphism, as illustrated in the views of its two principal exponents, G. Barrow and E. B. Bailey.

The chief points in Mr. Barrow's interpretation are:

- (a) The stratigraphical sequence corresponds in general to the structural sequence, and is uninverted, so that the lowest rocks are found along the Highland Border.
- (b) The metamorphic zones are of the nature of thermal aureoles surrounding centres of 'Older Granite' igneous activity.' The distribution of the zones is, therefore, in direct relation to such centres.

Now, in all the region mapped in Perthshire and Argyll, there is but one solitary record of the existence of an 'Older Granite' intrusion: namely, in the small intrusion of Dunfallandy, south of Pitlochry. One is, therefore, led to believe that the distribution of metamorphism for this region bears no such relation as Barrow has indicated. The manner of superposition of the zones is, furthermore, the reverse of that expected on his interpretation.

This is not to state that the 'Older Granite' activity is totally unconnected with the Dalradian metamorphism. In those areas in which such intrusions are abundant, the magmatic influence doubtless plays a part, and it may be noted that, if the inverted succession be accepted, the intrusions have entered in those regions

which, at an early stage in Dalradian history, were buried at

greater depths.1

Mr. Bailey's views on Dalradian metamorphism are so intricately interwoven with his conception of the structure of the Southern Highlands, that it is somewhat difficult to disentangle them. If I have understood them correctly from his published papers, then

(a) The metamorphic zones (these do not bear the same indices as those of Barrow) are superimposed one upon the other, in order of increasing

crystallization from above downwards.

(b) The great overthrusts which he has recognized do not interrupt the metamorphic gradients of the district through which they pass, whence it is inferred that such movements were contemporaneous with the metamorphism.

Let us take the concrete example of Cowal, which is included in the area dealt with in this paper. The zonal indices developed by Bailey are (1) Mica inconspicuous, (2) Mica conspicuous, (3a) Mica with garnet, and (3b) Mica with albite. I must confess to believing that, with the exception of garnet, these indices have little quantitative value, and that the use of albite is distinctly misleading for the area in question, having little or no metamorphic significance. By its abundance it marks out a peculiar type of sediment, the interest of which is here mainly stratigraphical.² But, following in part the views of C. T. Clough and in part those of E. H. Cunningham-Craig, Mr. Bailey has associated the metamorphism of the Cowal area with the formation of Clough's anticline, so that the maximum belt of metamorphism is found along its axis (albite-schists predominating).

It will be obvious that, if the inferences which I have drawn for Perthshire hold also for Argyll, the spatial distribution of metamorphic zones is not in accord with the metamorphic distribution assigned by Bailey. Indeed, if these inferences be pursued, it is conceivable that the metamorphism in Cowal bears no direct relation to the axial belt, that the zone of maximum metamorphism in any case lies farther north-west, and that the garnet zone itself

may even be synclinally disposed.

With regard to the overthrusts, an important one is recorded by Mr. Bailey close to the south-eastern shore of Loch Fync, and this

¹ Mr. Barrow has prepared a map (reproduced in F. H. Hatch's 'Text-Book of Petrology' 6th ed. revised, 1910, p. 290) showing the area permeated by veins of the Older Granites, for the South-Eastern and Central Highlands. This permeation-area is depicted extending as far south-west as Pitlochry. The small intrusion of Dunfallandy, south of Pitlochry, represents the south-western outpost of Older Granite intrusions in the Southern Highlands.

² Mr. Bailey follows E. H. Cunningham-Craig (Q. J. G. S. vol. lx, 1904, p. 10) in believing that garnet bespeaks a more thermal, and albite a more hydrothermal, condition of regional metamorphism. I am unable to discern any adequate reason for this suggestion. In the pelitic rocks of Cowal and the Loch Lomond area, albite is found abundantly in all of the three zones of

chlorite, biotite, and garnet.

has been taken as the limit of my zonal map. Before the nature of the metamorphism on either side of this line can be profitably discussed, a detailed metamorphic survey of the Dahnally and Kintyre regions will be necessary; but that part of it which I have examined leads me to believe that the second of Mr. Bailev's

conclusions here cited is not less open to question.

In the neighbourhood of St. Catherine's, the strongly garnetiferous Ben Lui Schists end abruptly against the Ardrishaig Phyllites, which along this part of the coast are in a low state of metamorphism. All this might be gathered from the detailed descriptions by Clough, given in the Cowal Geological Survey memoir. From a study of this memoir, there also emerges the fact that a belt of Green Beds is developed in rocks which Clough identifies as Ardrishaig Phyllites, between Midletter and Newton Bay. For this reason, Mr. Bailey transfers a narrow zone containing them from the Loch Awe Series to the Cowal succession. It may also be remarked that Clough refers to points within this area, where the Ardrishaig Phyllites carry both biotite and garnet. I have followed Mr. Bailey in his transfer of these beds, but scarcely for the same reason: for it is clear from examination that they represent sediments in a distinctly higher grade of metamorphism. If, then, a further examination of this line along its outcrop supports the evidence supplied in these localities, the period of overthrusting belongs to a later stage in the history of the Dalradian sediments, and may be comparable with the overthrusts of the North-Western Highlands.

A consideration of the results acquired during this preliminary survey leads me to state that no detailed support can be given, so far as this region is concerned, to the manner of metamorphism conceived by Mr. G. Barrow, nor yet can these results be held to confirm the deductions of Mr. E. B. Bailey. The zonal indices of the latter are not accepted as giving evidence of the degree or

disposition of the true metamorphic horizons.

Is it unreasonable to suggest that the metamorphism of this region was essentially acquired at a stage in Dalradian history when the disposition of the zones was in approximate accord with the depth of burial of the sediments, and that movement has been prolonged beyond the metamorphic period, leading here not only to inversion of the sequence, but also to inversion of the zones?

IV. BIBLIOGRAPHY.

G. BARROW. 'On an Intrusion of Muscovite-Biotite-Gneiss in the (1) 1893. South-Eastern Highlands of Scotland & its Accompanying Metamorphism' Q. J. G. S. vol. xlix, p. 330.

Id. 'The Geology of Lower Decside & the Southern Highland Border'
Proc. Geol. Assoc. vol. xxiii, p. 268.

E. B. BALLEY. 'The Structure of the South-Western Highlands of

(2) 1912.

(3) 1922. Scotland 'Q. J. G. S. vol. lxxviii, p. 82.

Id. 'The Metamorphism of the South-Western Highlands' Geol. (4) 1923. Mag. vol. lx, p. 317 [this paper contains a bibliography of the literature since 1893].

C. E. Tilley. 'The Facies Classification of Metamorphic Rocks'

Geol, Mag. vol. lxi, p. 167.

(5) 1924,

EXPLANATION OF PLATE IX.

Map illustrating the sequence of metamorphic zones in the Southern Highlands of Scotland, on the scale of 4 miles to the inch, or 1:253,440.

Discussion.

The Secretary read the following contribution to the Discussion, received from Mr. E. B. Bailey:—

'The Author's entrance upon the Scottish field of regional metamorphism is one of the most welcome occurrences of late years. His detailed work has already added much to our knowledge, and we look forward to further advances. At present, he has demonstrated to my satisfaction that in much of the South-Western Highlands a garnet-zone overlies a biotite-zone devoid of garnets. This is a new point of first importance. I believe the Author to think that it indicates a post-metamorphic inversion. With my wider knowledge of the South-Western Highlands, I do not regard this as a safe conclusion. For instance, I know of stratigraphical zones, such as the Ballachulish Slates, where the development of garnet is relatively delayed by chemical composition. I look forward to the Author's verdict in regard to this matter after he has studied Ballachulish.'

Mr. G. Barrow expressed his pleasure that the Author was continuing the work of the thermal zoning of the south-eastern portion of the Central Highlands. These zones had been found to continue in the same order in Ireland, in the area between Omagh and Londonderry.

The speaker dealt at some length with the thermal zoning of

these very old rocks, the chief points being :-

(1) This zoning had been found by him to be applicable to the entire Highlands, to the Isle of Man, and to Anglesey; all these rocks are of the same age, but show varying phases of thermal zoning.

(2) The Highland rocks fall naturally into three 'blocks' or

massifs.

The first is commonly known as the Central Highlands; its south-western boundary is that dealt with by the Author. The north-western boundary lies along the Caledonian Canal, and thence continues through Islay, separating the main and little crystalline portion from the smaller (though markedly crystalline) part on the north-west.

The second block extends from the Caledonian Canal to the

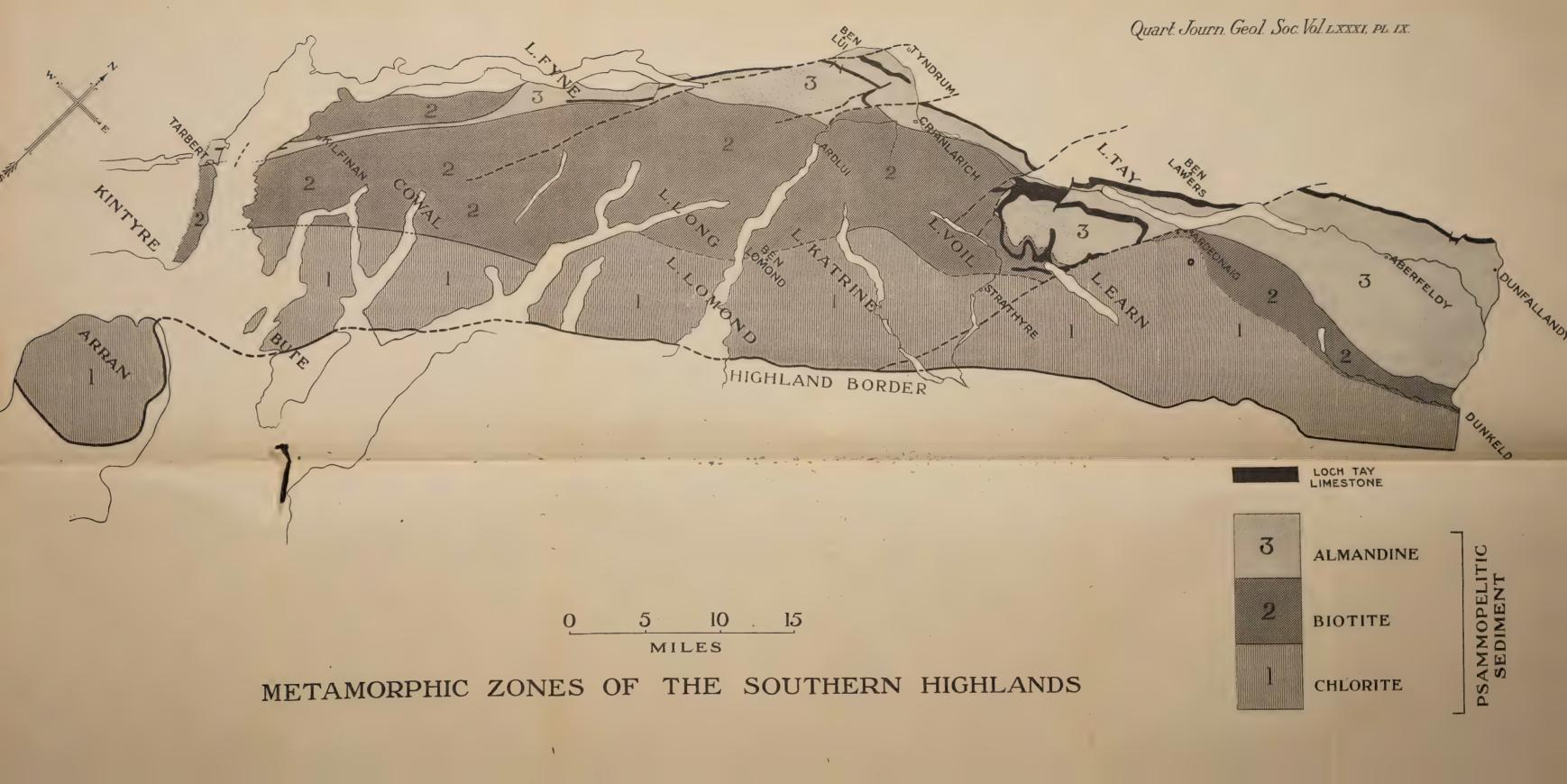
well-known Moine Thrust.

The third consists of the so-called 'Lewisian Gneiss' of the

mainland, lying north-west of the Moine Thrust.

The first block alone is complete; it has both of its uncrystalline edges still visible. The southern margin is that dealt with in this paper; the other margin is along the south side of the Caledonian Canal; proceeding south-eastwards thence, we pass over the thermal zones, exactly as in the southern side of the massif, but now the increase in thermal alteration is from northwest to south-east, the complement of that already mapped.

In the second block one side only of the original massif is still visible; this occurs along the south-east side of the Moine Thrust;





even here denudation has eroded all but a small belt outside the biotite-zone. The other margin is buried under the north-western edge of the Southern Highland Massif; the latter has been thrust into the second massif, so that in the south-western end of the Caledonian Canal the outer (uncrystalline) margin of the southern mass has been driven on to the sillimanite-zone of the second; the minimum distance of this overthrust must be about 5 miles, and may be very much more.

The third massif, the so-called 'Lewisian Gneiss', is remarkable, in that in the Durness area it is much more highly crystalline than any portion of the other two massifs; but this diminishes south-westwards, so that in the Loch Maree area the rocks are

within the kyanite-zone.

Now, if we start from the Moine Thrust in the Glen Elg area we come to kyanite-bearing rocks, so closely resembling parts of those in Loch Marce, that C. T. Clough had no doubt that they were of the same age. But they were held to be an inlier of the Lewisian Gneiss, and entirely separable from the surrounding rocks. There is no justification at all for this hypothesis; these Glen Elg rocks are exactly in their proper place in the scheme of thermal zoning: they are of Lewisian age, but so are the entire Highlands.

Similarly, south-east of Durness, there is another of these so-called 'inliers' of Lewisian Gneiss; it is much farther south-east of the Moine Thrust than that of Glen Elg: this would naturally be so, as it is characterized by sillimanite-gneisses, a thermal zone farther away from the Moine Thrust. Here, again, these gneisses are in their proper position in the thermal zoning of the country; they do not form an inlier at all, but here we are sufficiently far within the crystalline area to see the affinities of the rocks with the so-called 'Lewisian Gneiss'.

Briefly, the entire Highlands are of Lewisian Gneiss age; the loss of both the uncrystalline margins of the third and northernmost massif has led to the idea that it is of a different age from the other two. The Author's idea that all the zones are inverted implies the inversion of the enormous mass of rocks extending from the East of Scotland and south-westwards far into, if not across, Ireland, and this after they were crystallized. This does not seem at all probable; they may be locally inverted near one of the great faults. The other points raised can be deferred until the Author has visited some of the area mapped on the north-east. The question of the succession will be settled by internal evidence, and not locally.

Mr. E. H. CUNNINGHAM-CRAIG stated that, in order to understand the metamorphism in the area dealt with, it was necessary to

have a clear idea of the sequence of events.

These were as follows:—(1) Intrusion of pre-folding igneous rocks: (2) folding, formation of great fan-structure, accompanied by both dynamic and constructive metamorphism; (3) intrusion of older granites; (4) later shearing movements in areas susceptible to such movements; and (5) intrusion of later granites.

112

Each of the intrusions caused contact-metamorphism, and the effects of the various movements on the contact-zones, and of the relative and mutual effects of regional and contact-metamorphisms, have been studied and are well known.

A post-metamorphic reversal of the whole series would require the production of a recumbent fold too large to be conceivable: the overturning of a central fan-structure once formed seems quite

The wrench-faults are well known and understood; they are chiefly horizontal displacements, sometimes of as much as 6 miles. This movement took place in the 4th & 5th stages of the meta-

morphism.

The AUTHOR, in reply, said that, from an examination of the Baliachulish area, Mr. Bailey found that he cannot accept the evidence of inversion now brought forward, although he was ready to accept the evidence that the higher metamorphic zone of garnet was in Perthshire superimposed on lower zones of biotite and chlorite. The Author was unable to accept the metamorphic zones of Mr. Bailey, and, until that writer produced a detailed metamorphic map of the Ballachulish area, it was scarcely possible to deal with the supposed difficulties. He would not follow Mr. Barrow in his excursions throughout the Highlands, but would confine his remarks to the question of the metamorphism. sions of 'Older Granite' were conspicuous by their absence, not only in the area mapped, but also in the Schichallion area on the north, where the staurolite- and kyanite-zones were well developed. He thought that the 'Older Granites' were merely an incident in the metamorphism, entering as they did only in those areas which were the more deeply buried at the time of intrusion. They played no essential part in the metamorphism of the Southern Highlands.

Mr. Cunningham-Craig's criticism resolves itself practically into a restatement of the conclusions given by that writer in his paper on the metamorphism of the Loch Lomond region (1904). The Author could not agree with any of the more definite conclusions there reached. He was convinced that the albite-schists simply marked out a peculiar type of sediment, and were in fact a stratigraphical group. He contested the further points raised that the albite disappears close to the contact of Caledonian intrusives, that garnet and albite were antipathetic minerals, or that the genesis of these two minerals for this area required different types of metamorphism. Mr. Cunningham-Craig's conclusions were at variance with the facts which could be gathered on the ground, and also with

present-day conceptions of metamorphism.

The Author had not stated in the paper the mechanism of the inversion to which both Mr. Barrow and Mr. Cunningham-Craig had so strongly objected, but simply recorded the conclusions which appeared to follow from the tracing of the metamorphic zones. One possible method was that of recumbent folding, which was the essence of Mr. Bailey's structural conception of the South-Western Highlands. The view that the Perthshire structural succession was an inverted sequence was supported, he believed, by the data now brought forward.

[March 25th, 1925.]

5. Conditions of Deposition of the Stockdale Shales of the LAKE DISTRICT. By JOHN EDWARD MARR, Sc.D., F.R.S., For.Sec.G.S., Woodwardian Professor of Geology in the University of Cambridge. (Read November 19th, 1924.)

CONTENTS.

~		Page
Ι.	Introduction	113
II.	Lithology	114
III.	The Organisms	119
TV.	Conditions of Donosition	119
V	Conditions of Deposition	122
٧.	Summary and Conclusions	130
VI.	Petrographical Notes on the Stockdale Shales,	
	by Dr. R. H. RASTALL	131

I. INTRODUCTION.

A DETAILED account of these shales was written by the late Prof. H. A. Nicholson and myself, and some remarks upon their mode of deposition were made therein; but some further notes may be useful to those who are interested in the physical conditions under which sediments were accumulated.

The beginning of the deposition of the Coniston Limestone marks the start of a long period of sedimentation, characterized essentially by the accumulation of fine muds with nodular bands of limestone, as noted by Prof. O. T. Jones. The Caradocian portion of the Coniston Limestone contains much detrital matter of coarse character, with interbedded limestones; but in Ashgillian times the sediments were much finer, and these fine muds continued almost uninterruptedly, save by the above-mentioned lime-stones, to the end of Wenlock times. There are fine grits in the Browgill division of the Stockdale Shales, and the nodular limestone-bands are almost absent in the Brathay Flags, of Wenlock age. Otherwise, conditions of sedimentation, so far as supply of mechanical material is concerned, were very similar in Ashgillian, Valentian, and Lower Salopian times; and graptolites are found in the deposits of these three periods.

Details of the sediments of Ashgillian age will be found in a paper by myself,2 and of the Stockdale Shales in the paper to which reference has already been made. The following tabular statement

summarizes the facts:-

¹ Q. J. G. S. vol. xliv (1888) p. 654. ² *Ibid.* vol. lxxi (1915–16) p. 189.

	Thickness in fo	e e t.
SALDPIAN. Brathay Flags.	{ Black and grey mudstones with graptolites } about 100	00
VALENTIAN.	Browgill Beds. Greenish-grey mudstones, with red mudstones near the top: two beds with inconstant calcareous about 20 nodules.¹ Graptolitic shales, thin, grey rather than black (Dark (often black) graptolitic	0
Stockdale Shales.	Skelgill Beds. Shales, interstratified with five blue bands containing calcareous nodules and a thin limestone at the base	0
	(Ashgill Shales: blue mudstones, with occa-	
	sional calcareous nodules; fine grits at the base, no graptolites found	50
ASHGILLIAN.	calcareous nodule-bands 'White Limestone', with nodule-bands	16 12
	Phillipsinella Beds: dark mudstones, with nodule-bands	7

The wide distribution of these argillaceous sediments in this country and abroad, presenting generally similar characters whereever found, indicates that they were not coastal sediments, but were accumulated at some distance from the coast-lines.

After these preliminary remarks, attention may now be directed exclusively to the Stockdale Shales. It may be convenient for the reader to reproduce here the vertical section of the Stockdale Shales given in the paper by the late Prof. H. A. Nicholson and myself, Q. J. G. S. vol. xliv (1888) facing p. 706.

II. LITHOLOGY.

Nature of the deposits.—Apart from differences to be noticed presently, the various sediments of the Stockdale Shales are similar, in that their main constituent is a fine mud. This mud is, in the greater part of the Browgill Beds, and in a small portion of the Skelgill Beds, of a pale-green colour, and the other sediments differ from these in the nature of the colouring-matter. Such green sediments are frequent in the Lower Palæozoic rocks of this country as grauwacke-grits and muds, the latter being merely a fine variety of the former. They appear to be due to the abundance of felspar and ferromagnesian minerals in the rocks which supplied the sediment. The decomposition of these minerals would give rise to chloritic products, and the abundance of the minerals would result from the extensive exposures of rocks of igneous and metamorphic character.²

¹ Although these nodules are spoken of as 'calcareous', it is clear, as will be shown later, that the lime in the nodules of the Stockdale Shales has been largely replaced by iron.

² See J. A. Phillips, Q. J. G. S. vol. xxxvii (1881) p. 5.

Vertical section of the Stockdale Shales. (Scale: 1 inch=about 50 feet.)

	(((Coniston Flags.	
STOCKDALE SHALES,	ds.	Upper	Bb 2		
	gill Beds.	1	Bb 1—	-	
	Browgill	Lower.	Ba 2-		—Zone of Monograptus crispus.
			Ва 1—		—Zone of Monograptus turriculatus.
	18.	Upper.	Ac 5—		—Zone of Rastrites maximus.
	Skelgill Beds.	Middle.	Ac 4 — Ac 3 Ac 2 Ac 1 Ab 6 — Ab 5 Ac 3 Ac 2 Ac 1 Ac 3		-Zone of Acidaspis erinaceus. /Zone of Monograptus spiniyerus. /Zone of Ampyx aloniensis -Clingani Band. Barren BandZone of Monograptus convolutusZone of Phacops glaberZone of Monograptus argenteusZone of Encrinurus punctatusZone of Monograptus fimbriatus.
		Lower. {	Aa2-	Ashgill Shales.	—Zone of Dimorphograptus confertus. —Zone of Diplograptus acuminatus.
٠					т 2

The great uniformity in character of the detrital portion of the Stockdale Shale sediments is shown by the descriptions in the Appendix (§ VI, p. 131), for which I am indebted to Dr. R. H.

Rastall; see Appendix (B, D, F, G, & H).

Naturally, there are variations in the size of the component particles when traced from place to place, or at various horizons in the same locality, but in the area under consideration these are not great. Ordinary sandstones are absent, and the few deposits, chiefly found in the Browgill Beds, which approximate to grits, have the particles still so small that they may be spoken of as 'silts' rather than very fine grits. The great uniformity of character over wide areas is illustrated by a comparison of the thin green seam in the argenteus zone, often referred to as the 'green streak', with the corresponding band at Pont Erwyd described by Prof. O. T. Jones. Descriptions of the Westmorland 'green streak', and the corresponding seam at Pont Erwyd will be found in the Appendix (B, C).

The green beds being regarded as the normal deposits, three important variations marked by differences of colour are found: (1) black to grey graptolite-bearing mudstones; (2) blue non-

graptolitic beds; and (3) red beds.

Lines of nodules occur at various horizons. These nodules were once calcareous, but have largely been converted into carbonate of iron. They are absent from the graptolitic beds, occur abundantly in the blue beds, and one has been found in the green beds of the Browgill division, also another in the red beds of the same. Descriptions of the lithological characters of these varieties will be found in the Appendix (B, D, F, G, & H). From these descriptions, and the remarks made above, we obtain some idea of the reasons for the variations in the different kinds of sediments.

Taking the green beds as the normal deposits of the period in this area, owing their characters solely to the nature of the mechanical detritus which forms them, we must consider more

fully the variation in the black, blue, and red muds.

Black and grey graptolitic muds (see Appendix, latter part of B).—At one time, the dark hue of these sediments was considered to be due to the graptolites themselves. Prof. Charles Lapworth, however, maintained that these creatures were pseudoplanktonic, being attached to floating algæ of Sargasso type, and that the colouring-matter of the deposits was due to carbon derived from the 'weed', although he adduced no analyses in support of this view. Incidentally, he stated that these graptolite-bearing beds were deposited in deep and shallow water alike. the essential conditions being quietness of the waters. Allusion will be made to this point later.

¹ Q. J. G. S. vol. lxv (1909) pp. 489, 530.

² See his notes, in a paper by Prof. J. Walther, 'Ueber die Lebensweise Fossiler Meeresthiere' Zeitschr. Deutsch. Geol. Gesellsch. vol. xlix (1897) p. 209.

In order to settle the question of carbon-content, Mr. H. C. G. Vincent, B.A., kindly undertook the determination of the amount of carbon present in a sample of black graptolitic mudstone from the *fimbriatus* zone of Skelgill. He found 6 per cent. of carbon therein. Two determinations were made, the results showing 5.98 and 6.01 per cent. respectively.

Miss G. L. Elles has called my attention to the following analysis of a graptolitic mudstone, quoted by Prof. C. Barrois!:—

Schiste Ampéliteuse.

]	per cent.
Silica		64.1
		11.0
Carbon		11.0
		02.7
Water		07.2
	Total	96.0

In addition to the carbon, iron sulphide is also present in considerable quantity in the dark graptolitic muds of Lakeland, although, like the carbon, it doubtless varies in amount. That it is disseminated in a fine state through the rock is indicated in Dr. Rastall's notes, but a large amount is often visible to the naked eye in cubic crystals and crystal-aggregates. The importance of the presence of carbon and iron sulphide in these beds will be considered in the sequel.

Blue muds (Appendix, D & F).—It seems clear from Dr. Rastall's examination, that the colour in the case of these is due to iron carbonate, to the absence of free carbon, and to the paucity of iron-sulphide. It will be seen from his notes that the nodules which occur in these blue beds differ from the matrix in the smaller amount of mechanical detritus, as compared with the carbonate (Appendix, E). That the latter was once calcium carbonate seems clear, and it will be noted subsequently that these beds contain a fair number of lime-secreting organisms, a fact which is confirmed by the abundance of fragments of the same seen under the microscope. The nodules occur in definite stratified bands, and it is an open question whether they are of a concretionary nature, or due to the stretching of once continuous bands. As that point is not of importance in connexion with the matters discussed in this paper, I will merely remark that a certain amount of evidence seems to point to the latter conclusion.

Red muds (Appendix, H).—Many of the green muds of the Browgill Beds show superficial red staining along divisional planes, obviously produced subsequently to the deposition of the beds. Near the top of the Browgill Beds, however, is a fairly thick

¹ Ann. Soc. Géol. Nord, vol. xx (1892) p. 172.

deposit, well seen in Stockdale Beck and in Backside Beck, Cautley, which is uniformly stained throughout. That the colouring here is contemporaneous is indicated by the fact that it is entirely absent from the otherwise similar beds immediately above it, which mark a passage into the Brathay Flags of Wenlock age. The presence of a band with carbonate-nodules in this deposit is of interest.

Bedding-planes.-Though the deposits of Valentian age in this district are spoken of as 'Stockdale Shales', lamination is by no means a constant feature. It is most pronounced in the graptolite-bearing bands, but some of these (for instance, parts of the fimbriatus beds) do not show it in hand-specimens. It is not often conspicuous in the blue beds, although lamination appears in some cases, at any rate when they are examined in microscopic slices. The green and red beds also show intermittent lamination. In connexion with this, it may be noted that we frequently find beds of different character welded together with no plane of discontinuity; this continuous deposition, accompanied by a sudden change of conditions, is often found when a green or blue bed passes in this manner into a dark graptolitic bed. This furnished an additional piece of evidence that the mechanical basis of the sediments in the case of the different varieties is identical, and shows that the causes which produced the colour-changes were sudden.

One more reason for believing that the mechanical basis of the rock was essentially the same in each variety may be noted. The blue beds when weathered take a green hue indistinguishable from that of the normal green beds, and the dark graptolitic beds when subjected to the action of peat also lose their colour, and in every particular resemble the green beds which have been similarly affected. Further, the blue beds are occasionally replaced locally by green mud, as seen in parts of the *Ampyx* Zone of Browgill.

Vertical distribution of varieties of sediment.—Attention must be called to the relative proportions and vertical distribution of the different varieties of sediment. It is difficult to give an exact estimate of the relative proportions of the deposits, as they themselves vary along the outcrop, but the following is a rough approximation:—

	Perc	entage.
Grey to black graptolitic mud		10
Red muds		10
Blue muds		20
Green muds		60

The vertical sequence is of great importance. Tracing the beds from below upwards, we find the dark graptolitic muds predominating below, then the blue, thirdly the green, and lastly the red muds.

The Skelgill Beds consist of alternations of the dark and blue

muds, with thin streaks of the green, and no red. The dark muds are most abundant in the lower part of these beds, and the blue in the upper part. Furthermore, as the blue material increases and the dark diminishes in the higher beds, the former become (on the

whole) paler in hue.

In the Browgill Beds, the blue muds appear to be absent, the dark graptolitic muds are only found in very thin seams, and are usually of a lighter hue than those of the Skelgill Beds. The green muds form the bulk of the Lower Browgill Beds, while the red muds appear in the Upper Browgill division, though a small thickness of green beds above these marks the change towards the conditions which prevailed in Wenlock times.

III. THE ORGANISMS.

Let us now consider the light which the organisms shed upon the conditions of formation of the deposits. A list of these organisms will be found in the paper by the late Prof. H. A. Nicholson and myself, to which reference has already been made.

The beautiful state of preservation of the delicate graptolites strongly supports Lapworth's contention that the conditions were those of quietness of the sea-floor. This is also borne out by the preservation of the extremely thin tests of the Cephalopoda and the organisms referred to the Phyllocarida belonging to the genera Aptychopsis, Peltocaris, and Discinocaris. Some of these are found alike in the graptolitic and in the blue muds. The two basal plates of Aptychopsis and Peltocaris are constantly preserved separated one from the other, with a thin line of the matrix between them, showing that they were disconnected; but they are not displaced, as would have been the case if the slightest currentaction had affected them. The fact that the rostral plate has so

far remained undiscovered in these beds is puzzling.

The mode of preservation of the trilobites also suggests quiet conditions during the deposition of the beds, as one finds that an unusual proportion of these fossils are entire, or nearly so. There is one exception, which is itself illuminating: the Phacops-elegans Zone of Wharfe, near Clapham (Yorkshire), is almost entirely composed of trilobite-remains in a fragmentary state, forming a thin limestone, which probably represents one or more of the blue bands high up in the Stockdale Shales of the Lake District. Evidence points to this having been deposited nearer to the shore than its equivalent in the west, and it was probably affected by current-action in shoal water. I would suggest that the fossils of this deposit were originally embedded in mud, and that this was subsequently removed by current-action, leaving the fossils which would then become disintegrated, as a calcareous residue. Mr. W. B. R. King informs me that he has recently found the elegans zone near the head of the Crummack Valley, and that there the deposit is a blue mud like those of the Lake District, with trilobites also preserved entire or nearly so, as in that district.

For an account of a calcareous deposit formed under conditions somewhat similar to those which I have suggested above, I may refer to a paper by Mr. P. Lake.1

Leaving the evidence furnished by conditions of entombment,

we may consider the modes of existence of the organisms.

For our purpose, the chief distinction to be emphasized is that between the organisms living at or near the surface, and those living on or near the sea-floor. It will save words, if we speak of the former as plankton and of the latter as benthos, as these terms are conveniently used by geologists in a wider sense than

that attached to them by biologists.

Plankton.-Let us consider first the plankton. Here we are at once confronted by a difficulty, as it is not easy in the case of extinct organisms to distinguish those of planktonic from those of benthonic habit. The view of Lapworth, already noted, that the graptolites were pseudo-planktonic creatures attached to floating weed is now widely accepted, with the reservation made by him (and supported by Ruedemann) that some were truly planktonic.

I have been unable to detect any radiolaria in the Stockdale Shales, but their detection by Rothpletz 2 in the equivalent graptolitic shales of Langenstriegis (Saxony) and by others in various lark graptolitic shales of other periods in this country and abroad

s germane to our enquiry.

The planktonic existence of two groups of organisms in these rocks is suggested by the nature of their tests and, as will be subsequently seen, by facts connected with their distribution in the different kinds of sediment. I refer to the Phyllocarida and the Cephalopoda and, I may add, to the problematical Dawsonia. The tests of Peltocaris, Discinocaris, and Aptychopsis are marked by extreme tenuity, and the apparent absence of calcareous matter, the substance as now preserved suggesting chitin. The same may be said of the Dawsonia and Cephalopods referred to Orthoceras araneosum. I would note the large size of some of these creatures. Fragments of the Orthoceras mentioned show that the animal attained a considerable size, and an imperfect specimen of Discinocaris gigas indicates a carapace nearly 3 inches in diameter.

It has been suggested that some of the trilobites were planktonic; but evidence will be given that many of those of the Stockdale Shales lived in the bottom waters.

Benthos.-When discussing the benthos we are on more certain ground. The brachiopods and corals of these beds belong to the sessile benthos, and are particularly valuable as indices of conditions. Doubtless many of the trilobites swim freely at various depths: such are Phacops, Cheirurus, Encrinurus, Proetus, and Acidaspis. Others with extremely flat tests, such as Harpes,

¹ Proc. Camb. Phil. Soc. vol. xix (1918) p. 157. ²Zeitschr. Deutsch. & eol. Gesellsch. vol. xxxii (1880) p. 447 & pl. xxi.

Cyphaspis, and Ampyx. almost certainly lived in the mud of the sea-floor. The absence of eyes in the last-mentioned genus, and their curious modification in Harpes, Cyphaspis, and Arethusina, may have some connexion with the habitat of these genera. It is interesting to notice that these flat trilobites appear to be rare in, or absent from, the littoral sediments of Llandovery type, whereas the other genera first mentioned are frequent therein.

The actual or presumed benthonic creatures of the Stockdale Shales are distinguished by their dwarf size. One or two specimens of compound corals grew into fair-sized masses; but the solitary corals, brachiopods, and trilobites, which form the bulk of the non-graptolitic fauna, are very small as compared with their relatives of the shallow waters (see fig. 1). We miss the large Pentamerids, Orthids, and other common forms of these littoral deposits. Incidentally, one may note the non-occurrence of the horny brachiopods in the Stockdale Shales—a somewhat unexpected feature, considering their frequency in other graptolitic deposits.

Fig. 1.—Dwarf fossils from the blue muds of the Skelgill Beds; natural size.



[1=Ampyx; 2=Lindstræmia(?); 3=Meristellid(?); 4=Plectambonites(?).]

Not only are the benthonic fossils of small size in the Stock-dale Shales, but individuals are usually far from abundant. It is true that in the blue muds the microscope reveals numerous fossil fragments; but even here the deposits are barren, compared with many of those of the littoral, and the green beds yield very few fossil relics, so that it is perfectly certain that the sea-floor when these were deposited was unfavourable to abundance of organisms and their growth to large size.

In the case of the dark graptolite-bearing muds normal benthonic forms are practically absent. It is true that a thin seam 1 foot above the basal Atrypa-flexuosa Zone has yielded a few dwarf brachiopods and cirripedes, associated with graptolites; but here the conditions that prevailed during the deposition of the Ashgillian seem to have recurred temporarily. One specimen of a small Leptæna was found in the convolutus zone, in a somewhat

¹ A lithological description of the rock of the Atrypa-flexuosa Zone is given by Dr. Rastall in the Appendix (A). This zone may eventually have to be removed from the Stockdale Shales, and placed at the top of the Ashgillian division. Whether or no that is done, the conditions of deposition are a continuation of those of Ashgillian times, and therefore this deposit is not discussed in the present paper.

pale band of the graptolitic shale. Otherwise, the graptolitic bands which have been worked so assiduously, and which contain myriads of graptolites, have furnished nothing of normal benthonic character; and the absence of these is an additional argument for assuming a planktonic habit for the Phyllocarida and Orthoceras of which mention has been made.

IV. CONDITIONS OF DEPOSITION.

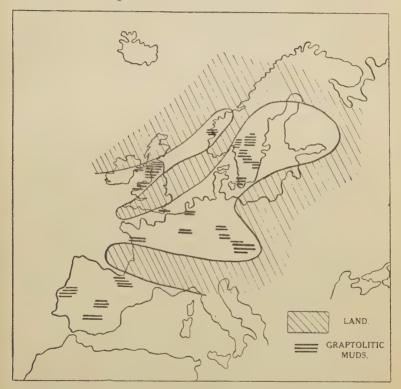
The deposits, especially the graptolitic beds.—The generally fine character of the muds of the whole of the Stockdale Shales undoubtedly indicates their accumulation at some distance from the coast-lines. It is true that there are lateral and vertical variations, but of small degree, and the above statement is substantially correct. As regards vertical variation, the evidence in the Lake District and neighbouring areas indicates a slightly coarser type of sediment as one passes upwards, pointing to a nearer approach of the land-margins towards the area under consideration in the later part of the period. Lateral variation is shown in the district itself, and suggests land lying in an easterly direction, as described by the late Prof. H. A. Nicholson and myself. Such lateral variation is still more marked when we pass beyond the confines of the district. On the north the Birkhill Shales are about three times the thickness of the corresponding Skelgill Beds, and on the south the equivalents in Central Wales have also a very much greater thickness. Variations of the same nature are also observable in the case of the Browgill Beds and their equivalents.

But, notwithstanding these differences, many of the lateral changes take place at the same horizon in these areas and elsewhere, as is so well illustrated by the 'green streak' and its

equivalent in Wales.

As the quiet conditions which marked the deposition of the sediments cannot be regarded as due to their formation in abysmal depths, embayments from the main ocean at once suggest themselves as a possible explanation. With this in mind I asked Miss G. L. Elles, D.Sc., to plot upon a map of Europe the places of occurrence of the dark graptolite-bearing muds of that age. This she has kindly done, and the result is shown in the accompanying map (fig. 2), whereon also the general position of the coast-lines is represented, as shown by the distribution of the coastal deposits and other features. These coastal deposits are, for the sake of clearness, not shown in the map; they form a fringe around the shore-lines. The map is to some extent hypothetical, although the general lines of the coast are indicated as the result of convincing evidence. The promontory shown as extending from Scandinavia to Britain, might, so far as the distribution of the rocks is known, have been broken by a strait, which separated an island occupying parts of Britain and adjoining tracts from the mainland on the north-east. This is unlikely, as, in the first place, it would give rise to very powerful surface-currents, and, secondly, because the upper deposits of the Stockdale Shale type of Valentian rock differ so markedly, as regards relative importance of the black graptolitic muds and the paler non-graptolitic muds in the case of the northern and central gulfs of the diagram. The matter is of small import, as it would produce little difference in the

Fig. 2.—Sketch-map, showing localities in Europe and the British Isles where the Stockdale Shales or their equivalents were deposited.



general coastal outlines as represented. So far as the British area is concerned, the coast-lines may be regarded as approximately correct. Judging by modern examples of large embayments, one may suspect the existence of festoon islands, off the seaward ends of the gulfs, increasing the quiet of the interiors.

In the quiet waters of such gulfs the fine sediments of the Stockdale Shales and their equivalents might well be formed, and the floating vegetation collected. Such a view of the mode of deposition of these strata accords with Mr. E. E. L. Dixon's idea

concerning the mode of formation of some of the Carboniferous rocks of South Wales and elsewhere, which present many points in common with some of the sediments here described.¹

Mr. W. B. R. King has indeed already suggested the formation of certain graptolitic shales of the Berwyn Hills under conditions

similar to those postulated by Mr. Dixon.²

A matter of great importance is the cause of the frequent and sudden appearance and disappearance of the algal material, regarded as the origin of the colouring of the dark graptolitic mud. This was to some extent rhythmical, although the periods of each were sometimes long, at other times very short. In the Skelgill Beds the period of formation of the dark beds was comparatively long,

in the Browgill Beds short.

As already pointed out, a change of type was often simultaneous over wide areas, but certainly not over the whole of the region represented in the map. For instance, the graptolitic beds of Valentian age in Bohemia show the continuance of the dark colouring-matter, the presence of graptolites, and the absence of benthonic forms throughout Valentian times, the equivalents of the Browgill Beds being also essentially of this type throughout, although green 'streaks' occur therein; and the same feature is noticeable in parts of Scandinavia. This would indicate that the change was not accompanied by, and due to, variations in temperature; and the most reasonable explanation is that it was due to change in direction of the sea-currents, which at times carried the weed into the embayments, and at others failed to do so.

The importance of the dwarf nature of the benthonic fauna and of the paucity of individuals has already been emphasized.

This benthonic fauna, as stated, is most important in the blue beds and part of the red beds, very sparse in the green beds, and practically absent from the dark graptolitic beds; and it has presumably some connexion with the conditions which caused the colour-changes.

The general paucity of the benthonic fauna and the dwarf nature of the animals is not due to the muddy habitat, for there are similar muddy sediments in deposits of many ages containing

abundance of benthonic life.

Marked difference of salinity from that of the open ocean is naturally suggested. We find nothing in support of great increase of salinity in the deposits themselves; and that the waters were not markedly different, in respect of saltness, from those of the open ocean is clearly indicated by the fact that the benthonic forms of the coastal belt are of normal size, and show abundance of individuals.

The most reasonable explanation is that quiet conditions in the

¹ E. E. L. Dixon & A. Vaughan, 'The Carboniferous Succession in Gower, &c.' Q. J. G. S. vol. lxvii (1911) p. 511.

² W. B. R. King, 'The Upper Ordovician Rocks of the South-Western Berwyn Hills' *Ibid.* vol. lxxix (1923) p. 494.

parts of the gulf away from the littoral belt, and beneath the superficial waters, which would be affected by moderate wind- and current-action, would operate, and give rise to a condition of stagnation, causing the lower waters to be charged with deleterious substances, which (for convenience) we may speak of hereafter as poison. This at some times (namely, during the accumulation of the dark graptolitic muds) was fatal to benthonic life; at other times, during the deposition of the green and some of the red muds, highly inimical; and only moderately harmful when the blue muds were laid down.

It has been seen that the absence of a benthonic fauna in the graptolitic beds is accompanied by the formation of carbon and much iron sulphide in them, for the iron sulphide is evidently contemporaneous, as shown by the occurrence of abundant graptolites preserved in relief in iron pyrites. Had the pyrites been formed later, the graptolites would certainly have been flattened.

At this point, we may briefly consider the conditions now prevalent in the Black Sea, of which a useful summary is given in the Guide to the Excursion of the VIIth International Geological Congress, published at Petrograd in 1897, chap. xxix. It is interesting to note that this inland sea has a maximum depth of 1227 fathoms, which may truly be termed abysmal.

The floor is covered with black mud, which receives much plankton from the surface-waters. Bacteria flourish on the decomposing organic matter, and their presence accounts for the formation of sulphuretted hydrogen, which poisons the lower

waters and forbids the existence of benthonic life.

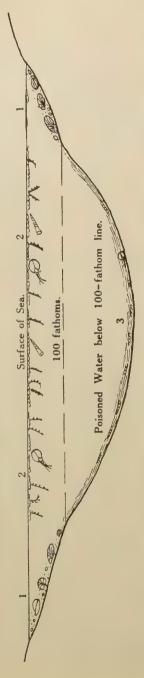
Life is, therefore, limited to the disturbed upper waters above the 100-fathom line: below this lie the stagnant poisoned waters.

Analogy with the black graptolitic bands of the Stockdale Shales is obvious. The deposit of fine mud, abundant plankton, supply of decomposing organic matter by the algae and graptolites sinking to the muddy floor, and consequent development of sulphuretted hydrogen shown by the abundance of iron sulphide in the beds, are similar in each case.

We must not, however, push this analogy too far. The map (fig. 2, p. 123) does not indicate merely landlocked water-tracts in which the Stockdale Shales and their equivalents were deposited, but more open gulfs; and one suspects that in that 'age of algæ' these plants played a more important part in geological operations than at the present day, and might give rise to conditions causing abundant development of iron sulphide in seas more open than the Black Sea.

Another apparent difference should be noted. As one result of the various chemical reactions which ultimately produce iron sulphide, calcium carbonate is precipitated in the Black Sea muds. No evidence of such precipitation has been found in the case of the graptolitic shales. Since writing the above, my attention has been called to a remark made by Prof. W. W. Watts in the

Fig. 3.—Diagram representing the conditions which prevailed during the deposition of dark graptolitic muds.



[1=Littoral deposits containing large and abundant benthonic forms. 2=Alga, with pseudo-planktonic graptolites, also planktonic cephalopods and Phyllocarida. 3-Lifeless sea-bottom with black muds, wherein dead planktonic and pseudo-planktonic organisms, which have sunk from the surface-waters, are entombed.] discussion of Mr. King's paper to which I have already referred.1 There Prof. Watts suggested that 'Black Sea conditions' may have prevailed during the deposition of the graptolitic shales of

Gwern-y-Brain.

The accompanying figure (fig. 3) is an attempt to show diagrammatically the conditions which prevailed in the coastal belt, the upper waters of the more open tracts of the gulfs, and the deeper water at the bottom of the same, during the formation of the dark graptolitic muds. The 100-fathom line is taken as separating the poisoned waters from those which by agitation are poison-free, simply by comparison with the conditions at present prevalent in the Black Sea. It may, of course, have varied considerably from this, being governed by the depth to which such agitation proceeded.

The blue beds. - We may next consider more fully the blue beds. In these, as stated, the benthonic life is most abundant, and has been responsible for the accumulation of a fair proportion of calcium carbonate, afterwards chiefly converted into iron carbonate by metasomatic change. The formation of iron sulphide has now largely ceased, for the amount is very small when compared with that of the graptolitic muds. Nevertheless, as stated before, the fauna is impoverished, when compared with that of the coastal belt. The explanation which I venture to offer is that a large part of the iron hydrate of the waters of the graptolitic-mud periods had then been converted into sulphide; and accordingly, at the end of each period of deposition of the black muds, the sea was sufficiently free from iron hydrate to allow of the existence of a moderate benthonic fauna, but the iron was still present in sufficient quantity to prevent a normal one. In other words, the iron hydrate, unlike the sulphuretted hydrogen, was in some degree poisonous, but not a fatal poison. Thus, in the Skelgill Beds, we find each deposit of graptolitic mud succeeded by one of blue mud; and in the Browgill Beds the graptolitic bands of the crispus zone are shortly succeeded by a band with nodules. It is true that no graptolitic zone has been found immediately beneath the deposit with nodules in the red beds; but there are, outside the Lake District, graptolitic bands in the equivalents of the Upper Browgill Beds which have not yet been detected within the district itself. These may have produced the same effect.

The green beds.—The green beds have a very sparse and dwarfed benthonic fauna, consisting of a few minute brachiopods. I have argued that these beds are composed of the normal mechanical sediments of the period, unchanged by addition of other colouring-matter. Why, then, the dwarf and sparse nature of the benthonic fauna? The most probable explanation, taking into account the evidence obtained from a study of the other

¹ See Q. J. G. S. vol. lxxix (1923) p. 544.

strata as to the presence of iron compounds in the waters, is that the iron in the waters when the green beds were deposited was there presumably as hydrate; but, as the conditions were not then favourable for its conversion into sulphide as in the case of the dark graptolitic muds, nor for its subsequent replacement in calcium carbonate by metasomatic action as in that of the blue beds, it remained in solution. It was able, however, to exercise its poisonous influence to a high degree, though not quite to the same extent as the more deleterious poison of the periods of formation of the graptolitic muds.

An apparent difficulty in this explanation is the occurrence of thin green streaks in the graptolitic muds. According to the arguments adduced, the waters should then have been fairly free from iron which had been already converted into sulphide. Why, then, are these streaks green, not blue? I think that the explanation is that there was not time during the formation of these thin streaks for the distribution of calcareous organisms over the area. This seems to be borne out by the fact that the basal

parts of the blue beds are often, perhaps invariably, green.

The red beds.—Lastly, an explanation is required for the red beds. Their existence, on first consideration, suggested complete severance of the region where they are developed from the open sea, and colouring of the sediments by iron oxide in an inland basin. If any such severance took place, it did not cause increase of salinity sufficient to obliterate the marine organisms, for small brachiopods are scattered throughout, as in the green beds, and a fairly abundant though small benthonic fauna, comparable with that of the blue beds, is found in the portion of the red beds

characterized by nodular bands. These beds, in regard to lithological characters, colour, and fauna, strongly resemble the Caerfai Beds and also certain red shales of the Old Red Sandstone in Carmarthenshire containing Leperditia, shown to me by Dr. H. H. Thomas. The explanation of the origin of the latter especially, which still seems to be a disputed question, will probably apply also to these red beds of the Stockdale Shales. Their comparatively limited distribution shows that the conditions, whatever they were, were local. It must be remembered that in the upper part of the Valentian Period (Gala stage) the Southern Upland region of Scotland was receiving, not muddy sediment so much as grit, which accumulated to a great thickness. The deposition of this would cause the seas to shallow, and perhaps to be completely silted up in places. It is possible that such silting towards the mouth of the northern gulf gave rise to shoal-waters which may have formed a partial or even complete barrier across its mouth.

Contrast with coastal deposits.—If the suggested explanation of the mode of formation of the Stockdale Shales and of the beds of the same age elsewhere having similar characters

were correct, we should expect to find deposits showing intermediate characters as regards sedimentation and organisms in a belt between the coastal and the deep-water tracts. Such passage-beds do occur. Dr. H. Lapworth records a mixture of graptolites and benthonic organisms in certain beds of the generally graptolitic Valentian strata of the Rhayader district, which lie between the more exclusively graptolitic beds of the Pont Erwyd district and the coastal deposits of the Welsh Borderland; and I have seen this intermixture in Valentian graptolitic shales of Gulleråsen and Kallholn in Dalarne, where there are again evidences of approach to the coastal belt. This mixture is, of course, known in many dark graptolite-bearing muds of other ages.

The extreme rarity of the benthonic fossils in the graptolitic beds of Lakeland has been noted. Conversely, the graptolites are extremely rare, though not altogether absent, in the coastal belt, where the carbonaceous matter is wanting. The absence of algal matter and the rarity of graptolites in this belt is probably in part due to mechanical destruction; but it is probably, to a very great extent, due to the consumption of the algae by phytophagous creatures, and possibly to a similar consumption of the graptolites

by various animals.

Graptolitic deposits of other ages.—At the end of Valentian times, the conditions producing dark muds with graptolites and scarce benthonic life set in, and continued uninterruptedly in many places throughout Wenlock times. The distribution of these beds extends over wider areas than that of the black graptolitic beds of Valentian age, indicating that, although the land-tracts of Europe in these later times were in general a continuation of those that existed in the Valentian period, seatransgression occurred, and thus the extension of the gulfs would be wider. This in itself points to the formation of these graptolitic beds in areas which had only a remote resemblance to the Black Sea.

Indeed, the study of graptolitic deposits of various dates, especially those of Arenig and Llandeilo times, indicates that the necessary conditions were often found over very large areas. The dominant factor in the production of dark graptolitic shales was almost certainly the existence of great masses of floating alge, and, as suggested before, this was probably a phenomenon which occurred in Lower Palæozoic times to a greater extent than before or since.

In the period that we have been considering, it will be found that the graptolitic muds are more fully developed in the more open tracts of the middle and southern gulfs than in the narrower northern one. In Bohemia and other places of the middle gulf, the dark graptolitic muds were deposited in a succession almost

 $^{^1}$ 'The Silurian Sequence of Rhayader ' Q. J. G. S. vol. lvi (1900) p. 67. Q. J. G. S. No. 322. $\,^{\rm K}$

unbroken (being interrupted only by the formation of thin green streaks) from the beginning of Valentian to the end of Wenlock times, and in a modified degree during Lower Ludlow times also. In other words, the narrow gulf of the north seems to have been to some extent inimical to the formation of the dark graptolitic muds, which are there largely replaced by blue, green, and red muds. To these latter alone, the narrow gulf-like conditions appear to have been important.

V. SUMMARY AND CONCLUSIONS.

The Stockdale Shales consist essentially of fine mud deposited in still waters away from the coastal belt. The matrix is fine mechanical sediment derived from the erosion of rocks of igneous and metamorphic origin. There are alternations in the deposition of four kinds of sediment; but, generally speaking, dark graptolitic muds mark the lowest Stockdale Shales, followed in order by blue, green, and lastly red muds.

Benthonic organisms are practically absent from the grey to black muds, very rare in the green, more frequent in the blue and in some part of the red: these are always dwarfed. Planktonic and, in the case of the graptolitic beds, pseudoplanktonic organisms

occur, the former sometimes of large size.

It is argued that the paucity of benthonic life and the small size of the individuals is due to poisons. The poisonous effects varied in degree at different times, being most pronounced in the periods of formation of the graptolitic shales, next in the green beds, and least in the blue beds. The poisonous matters existed only in the deeper water, the waters nearer the surface being poison-free, owing to agitation by waves and currents. Hence the planktonic and pseudoplanktonic organisms could flourish in those parts of the upper waters which lay away from the coastal belt; while in the coastal belt itself, where the sea-bottom was less than 100 fathoms deep, a benthonic fauna existed containing organisms of normal size.

A map is given showing the distribution of the dark graptolitic muds, which indicates that Western Europe was indented by three gulf-like extensions of the ocean. In these the algal matter, which is believed to account for the flourishing of the graptolites, concentrated; but it would appear that such gulfs are not necessary for the occurrence of the algal matter, which may well have been more widely distributed in the open waters of the

Lower Palæozoic Era than in those of other periods.

This paper is concerned with beds of limited vertical thickness in a restricted area; but I believe that the results put forward will throw light on the Lower Palæozoic deposits as a whole. It would appear that the bulk of the Lower Palæozoic sediments, like those of the Stockdale Shales, were deposited within the mudline, and that abysmal deposits of organic origin are absent. Indeed, the principal limestones lie inside the mud tract, and are more coastal in character than the fine muds. Many of them were probably laid down in shallow-water tracts, where, for various reasons, mud was not carried; of such a nature, for instance, is the Wenlock Limestone. But it is probable that much pure or fairly pure calcareous sediment is due to subsequent removal of the mud from deposits which were originally a mixture of mud and calcareous matter. All the evidence convinces me that the coastal tract was one of accumulation of conglomerates, sands, and limestones, with occasional muddy silts, and that outside this was the great mud-belt, in which muds of the Stockdale Shale type were deposited.

I am greatly indebted to Miss G. L. Elles, D.Sc., Mr. W. B. R. King, M.A., and Dr. R. H. Rastall, M.A., for assistance of various kinds, only some of which has been noted in the text.

VI. APPENDIX.

Petrographical Notes on the Stockdale Shales. By Robert Heron Rastall, Sc.D., F.G.S.

[The specimens are described in stratigraphical order, beginning with the oldest. The numbers between square brackets are the catalogue-numbers in the Sedgwick Museum, Cambridge.]

A. Atrypa-flexuosa Zone, Skelgill.

This consists in part of finely-divided micaceous material, with chlorite of the usual type, and some quartz; but there is also a considerable amount of carbonate, and the rock effervesces freely with cold dilute acid. It differs therefore notably from the others, and may be described as an impure limestone [20,008].

B. Green Streak, Argenteus Zone, Skelgill (with parts of adjoining graptolitic mud-bands).

This specimen shows very pronounced colour-banding. The pale greenish-grey 'streak' is strongly differentiated from the other part, which is dark-grey. On ignition for 30 minutes, the 'green streak' becomes somewhat paler, nearly white; and the dark bands are reddened.

Under the microscope the 'green streak' is seen to be closely similar to the Browgill Shale (G, p. 132), though of somewhat finer texture, and with much more pronounced orientation of the flakes of mica and chlorite. Grains of quartz determinable under

a half-inch objective are quite rare.

The dark rock enclosing the streak, which belongs to the graptolitic bands, appears to be essentially of the same composition, although the structure is partly obscured by the presence of a large amount of dark brownish-black material. Since this reddens on ignition, it is probably in part ferrous sulphide and in part carbon [20,006].

ĸ 2

C. Green Streak, Pont Erwyd.

This is quite similar in composition and general character to the 'green streak' from Skelgill, but slightly coarser in texture: very angular fragments of quartz are easily visible in certain bands.

The rock is essentially an aggregate of quartz and very pale greenish mica and chlorite; the two last-named minerals differ only in their birefringence. There are also a few more or less rounded patches of chlorite of larger size. Carbonaceous material is scarce in most of the slide, but in one or two bands there are streaks and patches of irregular black flakes [20,007].

D. Phacops-glaber Zone, Skelgill.

This specimen shows well-marked lamination, and a considerable number of small calcareous fossil-fragments. There is also a good deal of general brown staining due to iron, which is occasionally concentrated into opaque vein-like streaks of very small width. In addition to the usual finely-divided chloritic and micaceous material, there is a considerable amount of carbonate, which (from its colour and very high refractive index) may safely be identified as mainly iron carbonate. At a rough estimate, this makes up about half of the rock. Visible quartz-grains are extremely rare, and very small. The whole rock, apart from the fossil fragments, is of very fine texture [20,005].

E. Nodule in the same.

The nodule shows just the same type of structure as the foregoing, including the lamination and narrow veins of iron oxide; but the proportion of carbonates is very much higher, so much so that it is difficult to make out the micaceous constituents, except under a high power. It appears to be, in fact, nearly pure iron carbonate [20,011].

F. Acidaspis-erinaceus Zone, Torver Beck, Coniston.

A blue-grey slightly iron-stained rock, which reddens decidedly on ignition. Microscopically, it differs mainly from G in the presence of a certain amount of brownish-yellow staining, due apparently to iron oxide. The other constituents are precisely similar, mainly white mica and chlorite, both of very small size; visible quartz-grains are also very small, and not numerous [20,004].

G. Browgill Shale, Browgill.

A pale greenish-grey rock of fine texture, not markedly laminated on a small scale, showing with a hand-lens only a few minute crystals of pyrites and some still smaller quartz-grains, with small flakes of white mica. When the rock was heated to redness for 30 minutes, the colour became slightly darker, with a faint pinkish-brown shade, probably due to dehydration of finely-divided ferric hydrate, or perhaps caused by dehydration of

chloritic material. The general appearance also became somewhat

more crystalline, and the mica more conspicuous.

In a thin section the rock is seen to consist of an irregular aggregate of minute flakes of white mica and chloritic material of a very pale greenish colour, with some small grains of quartz. There is but little orientation of the mica-flakes. Some rounded particles of a whitish substance are probably kaolinitic. A very small amount of some carbonate appears to be present. Certain square patches of red iron oxide represent pyrites, or perhaps marcasite. The rock seems to be entirely free from carbon, and the most abundant constituent is certainly some form of chlorite. This appears to be primary, but it is impossible to say whether any of the white mica is derived from it. The mica may be wholly of direct detrital origin [20,003].

H. The Red Bed, Backside Beck, Cautley.

In essential characters this rock is like the others, having a similar very fine texture and rather distinct lamination: in transmitted light it looks almost exactly the same as D (Phacopsglaber Zone), but by reflected light it is seen to be full of extremely minute brick-red particles. There is now only a very small quantity of carbonates, but it is of course possible, and even probable, that the red particles represent oxidized chalybite. The chief constituents are very finely divided mica and chlorite, together with the red iron oxide just mentioned [20,000].

DISCUSSION.

Miss G. L. Elles did not think that the conditions were altogether like those of the Black Sea, to which reference had been made, for there must have been free communication with the open ocean in order to let the graptolites get in. She drew attention to the part played by Zostera in furnishing the carbonaceous matter in the North Sea, and suggested that the graptolites might have lived attached to some plants, which, like Zostera, periodically broke away from their place of growth, and were then distributed far and wide by currents; these might well be swept gently into the gulfs and bays, and there come to rest with their living burden.

Prof. O. T. Jones said that they were greatly indebted to the Author for having given them his conclusions as to the mode of deposition of the Stockdale Shales, which he knew so well. Rocks of similar type occur in North Wales, and in passing southwards through Central Wales the Valentian rocks became much thicker and coarser, and showed various evidences of the approach of land in that direction. Changes of the same kind occurred, also, between the Lake District and the South-West of Scotland, and another land-area clearly lay in that direction. The shelly fauna in Wales was apparently restricted during the Lower Valentian, at any rate, to a narrow belt bordering the shore-line, and even then (as at Llandovery) there is a good deal of evidence that the fossils had

been drifted from their original habitat. It is possible that drifting would account also for some of the shelly fossils which he found in the Stockdale Shales. The striking changes of colour from dark grey to blue, and from blue to green, which occur in the Stockdale Shales at certain horizons, had been observed by the speaker throughout Central Wales when the graptolitic facies is developed, and suggested that they were brought about by physiographic changes near the shore-lines. It was satisfactory to find that, in the Llandovery district, which the speaker had recently examined, there are two well-marked unconformities in the Llandovery formation which are nearly, if not exactly, at the horizons where these changes of colour occur. The speaker was, however, compelled to disagree with the map which the Author exhibited to account for the changes in character of the Valentian rocks. particular, he would call attention to the facts that, in Scandinavia the shelly fauna occurred nearer the Christiania district, and the affinities of these faunas were with those of Girvan, and probably occurred along the same shore-line. The graptolitic faunas lav farther south in Southern Sweden, and were very similar to that of the Stockdale Shales. Still farther south lay the shelly facies of Gotland and Esthonia. Those of Gotland were closely allied to the shelly faunas of the Welsh Borderland, and probably occurred along the same shore-line. The Ordovician and Silurian shelly faunas appear to have been dispersed from the Baltic region along two coast-lines, one passing through the South-West of Scotland and the other through the Welsh borders. There is no evidence that the shelly faunas were able to migrate across the basin of deposition when the graptolitic deposits were accumulating.

The speaker believed that the land-mass of the Midlands was continued towards the Southern Baltic and Esthonia. Westward it ranged nearly east and west through South Wales, and, as the north-western coast-line ranged north-east and south-west, the two coast-lines must have approached close to one another. This circumstance may have given rise to an area of deposition having a restricted communication with the open sea, which the Author postulated to account for the character of the Stockdale Shales. The South-East of England, Britanny, and the Iberian Peninsula seemed to have formed a different province, in which Upper Valentian graptolitiferous beds lie unconformably on older rocks.

Mr. A. K. Wells compared the lower part of the Stockdale Shales with the Dolgelley Beds of North Wales. The latter also consist of blue and black beds; both are very pyritous, the sulphide having the form of layers of distinct crystals in the lower (blue) beds, but being disseminated throughout the upper (black) beds in a state of fine subdivision. As shown by Prof. Fearnsides in 1905, these rocks owe their intense blackness to their high sulphide content. Thus, lithologically, they are strikingly similar to the black beds in the Stockdale Shales, and, after hearing the paper just read one naturally suspected them of having been formed under 'Black-Sea conditions.' The paleontological evidence, however, negatives

this possibility, as they contain an abundant benthonic fauna, certain bedding-planes being crowded with trilobites, occasionally entire, but commonly represented by detached cranidia and pygidia, indicating disturbance by bottom currents.

He asked whether the Author would express an opinion on the probable depth of water under which such black pyritous clays

were accumulated.

Prof. P. G. H. Boswell welcomed the paper as a valuable addition to knowledge of the constitution of ancient sediments, and its influence on the life of the times. The fact that the paper was cautiously speculative was itself a recommendation.

The task which the Author had set himself was no easy one. If the cleaved and altered clayey sediments were excluded, then no more intractable rocks, from the point of view of petrological investigation, could be found in the British geological column than certain of the beds in the Stockdale Shales. New technique was

necessary to deal with sediments of this character.

Light on the existence of 'poisonous' conditions might be obtained from the results of recent dredging in the Irish Sea, where black sands and muds, fetid with sulphuretted hydrogen, were being produced. The sediments owed their colour to iron sulphide, the carbonaceous content being practically absent. On exposure to air and consequent oxidation, the material becomes pale yellow. In this case no accompanying deposition of calcareous material has been noted.

From the petrological standpoint, the poverty of the Stockdale Shales in those minerals which one might expect to have been derived from crystalline rocks, rather suggested that the detrital material was not obtained at first hand, but was yielded by pre-existing sediments and possibly volcanic material. Only the most

stable clayey minerals appear to have survived.

The persistence of grey-green bands, usually unfossiliferous, in the Valentian rocks over wide areas seemed to imply that the conditions then obtaining affected a considerable region. Such conditions might be produced by small earth-movements and climatic variations, leading to slight differences in the amount of iron, lime, magnesia, alkalies, silica, or carbon-dioxide dissolved in river-waters and thus brought down into the gulfs. Disturbance of chemical equilibrium, reacting doubtless with chemical changes induced by the lowly marine organisms of the time, might well have resulted in changes in the chemical composition of the fine-grained sediments and their absorbed compounds. Recent investigations served to indicate that some such causes influenced the deposition of calcareous mud, iron oxides and carbonates, felspars, and other minerals on the sea-floor.

Prof. A. H. Cox remarked on the close lithological resemblance between some of the black graptolitic shales and certain beds in other formations, such as the *Avicula-contorta* Shales of the Rhætic and the oil-shales in the Lower Carboniferous rocks of Scotland. Both of these groups occur among strata known to be of shallow-water origin; the Rhætic Series displays all the characteristics of 'lagoon-phase' deposits, while the oil-shales are associated with thick sandstones of shallow-water facies. Arguing by analogy, it would therefore appear probable that the graptolitic shales also represent sediments laid down in shallow water, during a period when the supply of sediment was temporarily decreased.

The PRESIDENT (Dr. J. W. EVANS) remarked on the interest of the employment of lithological and chemical details in conjunction with paleontological characters, in order to determine the conditions under which the rocks were laid down. He suggested that other Silurian areas (for example, that of North-Western France)

might be similarly investigated.

Prof. W. W. Watts also spoke.

The Author, in reply, admitted that the muddy floor and the depth of water had doubtless some influence on the character of the dwarf benthonic fauna. He had no idea as to the actual depth of the water-tracts, but the fact that many of the small trilobites had normal eyes seemed to forbid abysmal conditions. The existence of littoral deposits across Scandinavia in the provinces of Christiania, Östergotland, and Vestergotland, separating areas with black graptolitic shales on the north and south, suggested a land-tract against which the littoral deposits were formed. He did not consider that the mechanical sediments need have been derived directly from igneous and metamorphic rocks.

6. RIVER-TERRACES of the LOWER VALLEY of the WARWICK-SHIRE AVON. By Miss MABEL ELIZABETH TOMLINSON, B.A., M.Sc., F.G.S. (Read June 25th, 1924.)

[PLATE X-MAP & SECTION.]

CONTENTS.

	00112311200	
		Page
Ι.	Introduction	137
II.	Description of the Avon Valley Drifts	138
	(a) General Conspectus.	
	(b) Detailed Description.	
	(1) Fluvioglacial Deposits.	
	(2) Fluviatile Deposits.	
III.	Materials of the Fluviatile Gravels	154
IV.	Suggested Interpretation of the Avon Valley Gravels	154
V.	Points of Comparison with other River-Valleys	161
VI.	Bibliography	163
VII.	The Pleistocene Non-Marine Mollusca of the Avon	
	Valley, by Mr. A. S. Kennard & Mr. B. B. Wood-	
	WARD	164

I. Introduction.

SINCE the early part of the 19th century, the gravels which occur in the valley of the Warwickshire Avon have attracted attention. Strickland was one of the earliest workers on these deposits. He made many detailed observations, and recognized two main types of gravel. The high-level deposits which were unfossiliferous, and covered the hills, he considered to be of marine origin, while those occurring in the valley from 20 to 40 feet above the river, and containing mammalian remains and freshwater shells, he believed to be fluviatile (1, p. 103).1

Strickland attempted no further classification of the freshwater deposits; but his work is of great value, in that he carefully collected and identified organic remains from exposures, the position of which he described so accurately that they can be located at the present time almost with certainty. Strickland published lists of these fossils, together with their localities, and these have been

extremely helpful in the work covered by this paper.

About 1875 a paper was published by T. G. B. Lloyd (3) describing certain additional exposures in these gravels, but otherwise adding little to Strickland's work as regards the Avon river-

deposits.

Lucy (4) also described some new exposures in the Avon gravels. He states that two terraces containing mammalian remains occur in these valleys, one at 15 to 25 feet and the other at 40 to 50 feet above the present rivers; but he makes no reference to this

¹ Numerals in parentheses refer to the Bibliography, § VI, p. 163.

statement in his subsequent description of the gravels. His paper is chiefly concerned with a separation of the drift-deposits of this large area into those consisting chiefly of Oolitic detritus, and those containing northern material and flints, rather than with an investigation of the river-deposits.

These are the most important contributions to the literature of the Avon Valley Drift Deposits. A comprehensive bibliography of references to these gravels up to 1914 is given at the end of a

paper by J. W. Gray (5, p. 132).

Hitherto, only those gravels that have definitely yielded mambalian remains and freshwater shells have been regarded as of fluviatile origin. So far as I know, the Avon river-gravels have not been mapped in detail by previous workers, nor has any connexion been established between the various fossiliferous deposits—apart from their common mode of formation. The present investigation of the Avon Valley river-gravels was undertaken at the suggestion of Dr. L. J. Wills, F.G.S. An attempt has been made to map in detail the fluviatile deposits of the Avon Valley from Stratford to Tewkesbury, with the view of (1) demonstrating the existence of a series of river-terraces that may be traced down the valley at different heights above the river; (2) investigating the fauna contained in these terraces; and (3) using this stratigraphical and palæontological evidence as a means by which to deduce a history of the formation of the Avon Valley.

II. DESCRIPTION OF THE AVON VALLEY DRIFTS.

(a) General Conspectus.

All down the Avon Valley, from Rugby (6, p. 192) to its junction with the Severn at Tewkesbury, deposits of sand and gravel occur at different heights above the alluvium. These deposits appear to lie within a narrow belt, roughly parallel with the present course of the river. Moreover, they usually take the form of flat-topped or gently rising terraces, and in form and distribution strongly suggest earlier flood-plains of the Avon. These terraces have been mapped on the scale of 6 inches to the mile, from Stratford to Tewkesbury. There seem to be five distinct levels above the river at which fluviatile sands and gravels occur. When traced for some distance the top of each terrace maintains, on the whole, a marked constancy in its height above the present alluvium. the accompanying diagram (Pl. X, fig. 2) the maximum height above sea-level of the top of each terrace has been plotted to scale, and the thickness of the deposit shown where evidence has been forthcoming. The present thalweg of the Avon is represented by a curve joining heights (above sea-level) 1 taken on the alluvium as near the river as possible. The result shows terraces the tops

¹ All heights to which reference is made in this paper have been estimated by comparison with heights given on the 6-inch Ordnance Survey maps, which were used in mapping the deposits.

of which are at approximately the following heights above the river:—

No. 5: 140 to 150 feet.

No. 4: 80 to 90 feet.

No. 3: 40 to 50 feet.

No. 2: 30 to 40 feet.

No. 1: not more than 10 feet above the alluvium.

The reasons why the maximum heights of the terraces have been given rather than the base will be discussed in § IV, p. 155. Wherever possible, reference to the height of the base of a deposit will be made in the following description.

(b) Detailed Description.

(1) Fluvioglacial Deposits.

Still higher than No. 5 Terrace are large spreads of gravel which are found above 300 feet O.D. on Craycombe Hill, and above 350 feet O.D. round The Lenches. These occupy the highest ground in the district, and, if traced northwards, seem to merge into the glacial outwash gravels that have been mapped by Dr. L. J. Wills south of Birmingham. Where exposed on Craycombe Hill, between Evesham and Pershore, the deposit consists of bright red quartzose sand containing pebbles of banded rhyolite, quartz-porphyry, quartz, quartzite, and yellow sandstone. The first four were probably derived from the Bunter Pebble-Beds which occur farther north. Only one white-coated flint was noted, and there is a general absence of Jurassic detrital material, such as is so much in evidence in the river-deposits of the Avon Valley. On Badgers Hill (north of Craycombe Hill), the drift on the fields above the 350-foot contour appeared less sandy, and contained many Bunter pebbles; but no flints were noted. There is no direct evidence as to the thickness of this drift. It seems to cap the dissected plateau which lies north and north-west of the Avon Valley, and it is separated from the river-terraces by a considerable slope of solid rock.

(2) Fluviatile Deposits.

(a) Reasons for regarding No. 5 Terrace deposits as fluviatile.—In the absence of fossils, it seems advisable to state the reasons for regarding the deposits of No. 5 Terrace as fluviatile. In the first place, these deposits seem to occur roughly parallel to the line of drainage of the present Avon Valley, and in the diagram (Pl. X, fig. 2) the line drawn through the maximum heights is strongly suggestive of a river-gradient. Secondly, the materials of the gravel of Terrace No. 5 as seen on Welford Hill (p. 140) seem to be similar to those contained in the lower terraces, and distinct from the fluvioglacial gravels which occupy the plateau (p. 139). It seems, therefore, probable that drainage

operated along a line parallel to the present Avon Valley in the period when No. 5 Terrace deposits were laid down, and effected the deposition of these gravels.

(b) Description of the deposits of No. 5 Terrace .-Deposits of this terrace usually rest upon solid rock at about 120 feet above the alluvium, and rise to 140 or 150 feet above it; but in some cases there is evidence for the extension of the gravels to the level of a lower terrace. This seems to be the case at Strensham, between Pershore and Tewkesbury. In this district gravel appears to be continuous from 160 feet O.D. near Strensham Church to at least the level of Terrace No. 4, the top of which is about 120 feet O.D. in the neighbourhood. Round Strensham Church the gravel is only 5 to 6 feet deep; but in a field near the junction of the lane to Strensham Mill with the main road to Tewkesbury, about a mile south-west of the church, a boring of small diameter was made for water. A local engineer, present at the boring operations, told me that three lengths of gravel (each length was represented by a 14-foot rod) were passed through before blue clay was reached. As yet, I have been unable to obtain more reliable information concerning this boring; but observations on the superficial extent of the gravels near Strensham suggest a fairly great thickness of drift in this locality. For this reason, I have relegated all the gravels between 120 and 160 feet O.D. to one period of infilling of the valley. There is no surface-break between these two heights and, without more evidence, it is impossible to separate them into two series by any surface-feature. The section (fig. 1, p. 142) is drawn through No. 5 Terrace at Strensham.

Other deposits belonging to No. 5 Terrace appear to be separated from lower terraces by a slope of solid rock. The first occurrence of such deposits south of Stratford is the drift capping Welford Hill. The surface of the hill rises to 270 feet O.D. Lucy (4, p. 87) records 40 feet of drift on Welford Hill. A sand- and gravel-pit near the top exposed, in 1923, 6 to 7 feet of well-bedded sand and gravel. The sand was yellow, earthy, and ferruginous, sometimes almost passing into a loam. The gravel contained numerous flints and flint-chips, many quartz- and quartzite-pebbles, and a great abundance of ironstone pellets. The base of the drift

was not seen in this exposure.

No. 5 Terrace is represented in several other districts shown in the map (Pl. X, fig. 1); but in none of these are there good exposures now. About 1879, when the gravels on Green Hill, Evesham, were exposed, Mr. Winnington-Ingram (7, p. 678) recorded the presence of unworn flints weighing about 10 lbs., and attributed their presence to floating ice. The top of Green Hill is now flat and terrace-like.

Except at Strensham, all the deposits belonging to No. 5 Terrace seem to be separated from lower terraces by a slope of solid rock. There are no records of fossils or flint-implements from this level, and it is unfortunate that at the present time only one pit (Welford Hill) is working in No. 5 Terrace.

(c) No. 4 Terrace. - In the majority of places the base of No. 4 Terrace is about 70 feet above the alluvium, while the top is some 80 to 90 feet above it. Deposits referable to this terrace occur in patches along the Avon Valley, as shown in the map (Pl. X, fig. 1). Usually they form a capping to low hills, and in most cases the gravel seems to be separated from lower terraces by a slope of solid rock; but, owing to the creep of the gravel down the hill, it is not always possible to be sure of this. On the other hand, there are cases, as at Cropthorne, Luddington, and Cross o' th' Hill (Stratford), where No. 4 Terrace deposits seem to extend downwards to at least the level of the top of No. 2 Terrace, and to include deposits which (if we relied on evidence of their height above the river) would be relegated to No. 3 Terrace. It will be suggested in § IV (p. 157) that No. 4 and No. 3 Terrace deposits are possibly intimately connected; but, in order to keep these observed facts apart from any conclusions which may be drawn from them, No 4 and No. 3 Terrace deposits will be described separately here.

Deposits of No. 4 Terrace are exposed at Norton, north of

Evesham. On the east side of the Birmingham road, with a surface-height of 165 feet O.D., is a gravel-pit showing:-

Thickness in feet.

Soil Coarse gravel Beds of red sand and fine gravel 5+ (Clean silver-sand in parts.) Base not shown.

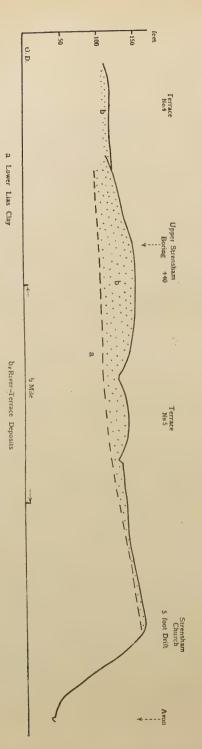
The sand varies in colour from pale buff to deep red, and from very clean loose silver-sand to partly cemented silver-sand.

and Bunter pebbles form the greater part of the gravel.

Gravels of the level of No. 4 Terrace occur again at Bengeworth Hill, near Evesham, where 5 feet of quartzose flinty gravel containing some Jurassic detritus, and showing no bedding, rests upon Liassic clay at about 145 feet O.D. Near Pershore, on the Avon bank, No. 4 Terrace deposits can be seen resting upon Lias, at about 130 feet O.D. Further deposits of this terrace occur at Mill End. Bredon, where there are several exposures of clayey ferruginous gravel containing Jurassic detritus, Bunter pebbles, and flints.

Near the junction of the Avon with the Severn is a large patch of sand and gravel extending from Shuthonger Common to near Brockeridge Common. It is exposed in an old pit on Shuthonger Common, showing about 7 feet of roughly-bedded gravel and seams of yellowish sand. The gravel contains Bunter pebbles, flints, and ironstone. According to Dr. L. J. Wills, the last two constituents are not usual in the Severn terraces above Tewkesbury. and thus the Shuthonger deposit may be regarded as a typical Avon river-terrace.

Fig. 1.—Section through No. 5 Terrace at Strensham.



From the areas of No. 4 Terrace deposits described up to this point there are no records of contemporary fossils; but it is probable that certain freshwater shells now in the Worcester Museum came from this level at Birlingham, between Pershore

and Tewkesbury.

Gravel caps the hill overlooking the Avon on which Birlingham Court stands. Freshwater shells were presented to the Worcester Museum by a Miss Porter about 1860, and occurred at a depth of 20 feet in a well 100 feet deep, situated on the bank of the Avon, at Birlingham. Gravels of the two lowest terraces (No. 1 & No. 2) also occur at Birlingham; but these do not form very high banks of the Avon through which it would be likely that a 100-foot well would be sunk. Several deep wells have been sunk in the Avon bank capped by No. 4 Terrace deposits at Birlingham Court. The present owner, Col. Porter, knows no details of the freshwater shells in the Worcester Museum; but he thinks that the 100-foot well mentioned in that report is now filled up, and was situated in the scullery of Birlingham Court. If this be so, and it appears very probable, we have here the only record of freshwater shells from No. 4 Terrace that has been noted up to the present in the main Avon valley; but shells have recently been obtained from this level in the valley of the Stour, a southern tributary which joins the Avon near Stratford. No. 4 Terrace of the Avon can be traced up the Stour for some distance. About 3 miles from Stratford, at Ailstone, a pit of sand and gravel occurs, with its surface about 75 feet above the Stour. The deposits consist of some 12 feet of yellow sand and gravel, overlying 4 feet of red sand and gravel containing freshwater shells, including Corbicula fluminalis and Unio littoralis. There was no noticeable difference between the constituents of the red and those of the yellow gravel, except that the shells seemed to be confined to the lower red deposit. The base of the gravel was not exposed; but it appears probable that it extends downwards to a considerable depth.

The remaining areas where deposits of No. 4 Terrace occur are those in which the gravels appear to extend from No. 4 level down to the level of the top of No. 2 Terrace. Of these the area round Cropthorne (Pl. X, fig. 1) will be considered in some detail. Gravel covers the hill (to about 150 feet O.D.) on which the village of Cropthorne stands. On the north-east side is the Rector's Pit. which was closed in the autumn of 1922. At that time 15 feet of drift was exposed, but the base was not shown. A workman said that excavation had been carried on in this pit to a depth of 30 feet, when clay was encountered. The surface of the pit is 130 feet O.D., and this would make the drift extend at least to 100 feet O.D. Lloyd (3, p. 212) mentioned a pit of stratified sand and gravel on the east of Cropthorne Hill. He said that the top of the pit was about 110 feet O.D., or 60 feet above the Avon. and the sand had been excavated for 30 feet below this without the base being touched, or any fossils being obtained. This would

make the base of the sand below 80 feet O.D. The following section was exposed in 1922:—

Thickness in feet	inches
Soil	8
Hard sand and pebbles 1	0
Many small pebbles in red clay, not	
Irregular hard sand, with gravel in places, but pebbles not numerous	0
Soft yellow sand	0

There was a change in the type of deposit between the hard red sand and the soft yellow sand. More pebbles were contained in the topmost deposit and included yellow flints, ironstone pellets, yellow micaceous sandstone, limestone, and soft, shelly, whitish shale (probably Lias). In the yellow sand were numerous fragments of hardened red and green marl (probably Keuper). From the base of the soft yellow sand, which was exposed in 1922 in the Rector's Pit to the highest point mapped on this terrace, is just over 35 feet. The actual base of the drift in the Rector's Pit is certainly much lower than the soft yellow sand—probably more than 15 feet lower, as stated by the workman (p. 143).

Thus, the height from the base of the gravel in this pit to the highest point marked on the terrace is very probably over 50 feet.

This exposure has been described at some length, because it may soon be overgrown; and the district round Cropthorne seems to be a critical one in the interpretation of the Avon river-terraces.

About 300 yards south-east of the Rector's Pit is another exposure of gravel, just above 150 feet O.D. Here about 14 feet of sand and gravel were exposed, there being much less gravel than sand. The gravel occurred in seams fairly horizontally arranged, with a few larger pebbles (6×4 inches) near the base. Quartz, quartzite, flint, pellets of ironstone and of oolitic limestone were noted. The sand was deep-red and clayey, like that at the top of the Rector's Pit. The height of the bottom of the pit is about 136 feet O.D., and thus only 6 feet need to be accounted for between the bottom of this pit and the top of the Rector's Pit. The soil and the surface-features suggest no break in the gravel between the two pits. The relation between these pits is shown in the section (fig. 2, p. 146).

Westwards the gravel extends to Cropthorne Heath, where a thickness of 7 feet of irregularly-bedded gravel is exposed in a disused pit. This exposure has been described in detail by Lloyd (3, p. 209). The highest point near Cropthorne Heath is 135 feet O.D., from which level the gravel slopes gently at first, and then more steeply, towards Bricklehampton Bank, where it rests upon a steep bank of Lias overlooking the river. The base of the drift is about 40 feet above the river, as shown in the section (fig. 3, p. 147). Unfortunately, all the old gravelpits on Bricklehampton Bank are overgrown; but, in the middle

of the 19th century, Strickland (1, p. 98) recorded two exposures, one in an old brickyard (now disused) and one 150 yards away to the east. From these he collected freshwater shells (of which a small collection is in the Worcester Museum) and mammalian remains.

Murchison (8, p. 556) recorded 20 feet of Drift on Brickle-hampton Bank, lying upon Liassic clay, and remarked that Strickland's shells were found 'from top to bottom of this varied coarse drift'. The bones were most abundant in the lower part, and were assignable only to Bos urus. Bricklehampton Bank really belongs to No. 3 level; but gravel extends continuously upwards to No. 4 level, and a dividing-line between the two levels would be arbitrary in this locality.

There are other cases between Stratford and Bidford where No. 4 Terrace seems to stretch down at least to the level of the top of No. 2 Terrace. One of these is immediately south of Stratford, at Cross o' th' Hill, and extends 2 or 3 miles up the Stour valley beyond Ailstone; the other is near Luddington (Pl. X, fig. 1). The only records of fossils from No. 4 Terrace are possibly the Birlingham shells (p. 143) and also the shells from Ailstone on the Stour (p. 143). Collections of shells from both localities have been submitted to Mr. A. S. Kennard & Mr. B. B. Woodward, who have examined the shells of these and other districts, and have given their report in an Appendix to this paper (§ VII, p. 164). Both collections probably indicate a climate warmer than that of the present time. Symonds (9, p. 35) speaks of a tooth of Mammoth being found on Shuthonger Common; but I cannot trace this, and so it is impossible to verify the identification. A complete list of the fauna from No. 4 Terrace is tabulated on p. 149.

(d) No. 3 Terrace.—This level of gravels is represented by small isolated patches of gravel, usually terrace-shaped, rising only 10 to 20 feet above the surface of No. 2 Terrace; but sometimes the downward continuation of gravels from No. 4 Terrace occupies this level (p. 141). Occasionally, the gravels seem to occupy lateral valleys cut through No. 4 Terrace as at New Inn, Cropthorne, and in the shallow valley containing the 'Old Fallow' pit between Little Comberton and Wick (map, Pl. X, fig. 1). In other instances, these gravels are separated from No. 2 Terrace by a distinct rise. This is the case with gravels under Littleworth Street, Evesham, near the cross-roads south-east of Chadbury, at Eckington (railway-cutting) and Bredon (flat on which the village stands). In only one case is there a good exposure at the present time in these gravels; but there were excavations at this level in several districts many years ago.

According to Lloyd (3, p. 214), $2\frac{1}{2}$ feet of gravel underlay 20 feet of brick-earth at Bengeworth near Evesham. This was worked in the old pit now overgrown and containing water, which lies in the fork between the road to Breforton and the lane to

Fig. 2.—Section through No. 4 Terrace, at Cropthorne.

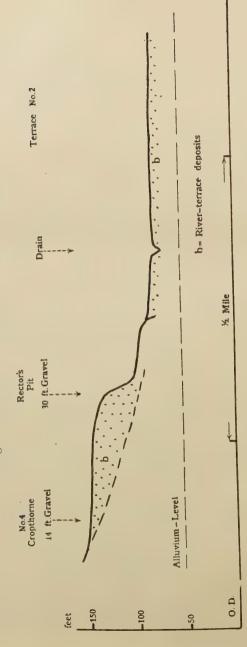
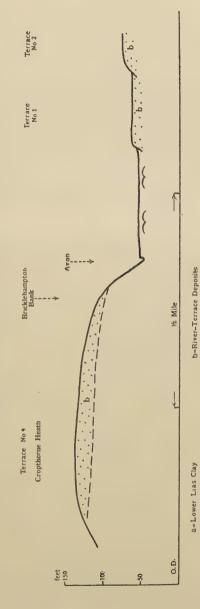


Fig. 3.—Section through Bricklehampton Bank, Cropthorne.



Badsey. The surface-level of the brick-earth in this pit was probably about 123 feet O.D., and the gravels were at about 103 feet O.D., resting upon Liassic clay. The whole deposit belongs, therefore, to No. 3 level. Winnington Ingram (7, p. 678) records unopened shells of *Unio ovalis* from the loam, and the following mammalian remains from the gravel:—entire head and horns of *Bos primigenius* and *Bison priscus*, antlers of *Cervus tarandus*, tusk of *Hippopotamus*.

At the present time the only good exposure in No. 3 Terrace is in a sandpit in Littleworth Street, Evesham, with a surface-height about 40 to 45 feet above the river. The deposit consists chiefly of sand, with subsidiary seams of gravel, 22 feet of which were exposed in 1922 without reaching the base. A jaw of Bos was found 16 feet below the surface in clear silver-sand, together with a few valves of freshwater shells. A few more valves of freshwater shells came from a bed of loam about 20 feet below the surface. The pit has also yielded a canine tooth of Pleistocene Wolf. Unfortunately, none of these supply definite evidence

of the age of the beds.

Dr. H. F. Osborn (10, pp. 407, 423) includes the Pleistocene Wolf in his 2nd (Hippopotamus, etc.) and 3rd (Mammoth, etc.) faunal divisions. Mr. Kennard & Mr. Woodward have examined the shells which represent only a few species (named in § VII, p. 164), all of which are common to No. 4, No. 3, and No. 2 levels. The few valves were dwarfed, and thus it is suggested by those authors that the valves belong to a later and colder period than that to which the other collections of shells from No. 3 level belong. This pit is still working, and it is possible that further material may confirm or modify this opinion. The Littleworth Street deposits are classed as No. 3 Terrace, because of their surface-height above the river and their relation to other No. 3 deposits, as shown in the gradient-diagram (Pl. X, fig. 2).

At New Inn, Cropthorne, a very fine section at No. 3 level was exposed when the Evesham-Pershore road was levelled early in the 19th century. The section yielded shells and mammalian remains, and was carefully described by Strickland (1, p. 95). The road-section gave a bed of fine sand $2\frac{1}{2}$ ft. thick, merging gradually into gravel. The shells, of which a full revised list of 30 species is tabulated in § VII, were confined to the sand, but the bones were also contained in the gravel. This drift was 11 feet thick in a field near the road, and some 7 or 8 feet thick in the road-section. The mammalian remains consisted of bones of

Hippopotamus, Bos, Cervus, Ursus, and Canis.

About a mile farther down the river is a shallow lateral valley, which contains only a very small short stream. Gravels occur in this valley as far south as Old Fallow Farm. A short distance north of this farm is the site of an old gravel-pit, which is now filled in and the surface cultivated. This is almost certainly the locality to which Lloyd refers (3, p. 213) when he speaks of the gravel-pit near Little Comberton being in a shallow valley

about a mile from the present river. Lloyd records 10 feet of sand and quartzose flinty gravel resting upon Liassic clay. Of freshwater shells found here by the Rev. William Parker, the Vicar of Little Comberton, there is no record; but a tusk of Hippopotamus now in the Worcester Museum came from this

pit.

The next patch of No. 3 Terrace gravels from which fossils are recorded lies immediately north of Eckington. Strickland (2, p. 141) records Elephas primigenius, Hippopotamus major, Bos urus, and Cervus giganteus, from the Eckington gravels, and says that they were found chiefly in the railway-cutting north of the village of Eckington: that is, in No. 3 Terrace. There may be some doubt about the identification of Elephas primigenius, because there is a molar in the Worcester Museum labelled Elephas antiquus (Falconer), Eckington. Dr. Humphrey Humphreys, M.D.S., confirms this identification. Strickland also recorded freshwater shells, which he said agreed with many of those found at New Inn, Cropthorne. Only two species (which Strickland said were most common) are named in § VII, p. 164.

LIST OF THE FAUNA FROM NO. 4 AND NO. 3 TERRACES.

(No. 3 Terrace + and No. 4 Terrace *.)

Canis sp. + Corbicula fluminalis Elephas antiquus (?) + Bithynia tentaculata + Hippopotamus + Valvata piscinalis + Ursus + Valvata cristata +	++++++	*** * *****
---	--------	-------------

Gravels of a similar height above the alluvium underlie the village of Bredon, but no exposure was noted. Wherever mammalian remains have been recorded from No. 3 Terrace (except at Bricklehampton Bank and Littleworth Street, Evesham) Hippopotamus has been among them (four localities), and in one place ossibly Elephas antiquus. At New Inn, Cropthorne, Strickland

found Belgrandia marginata (a warm-climate shell) and Unio littoralis, both now extinct in Britain. It is suggested in § VII that the shells from Cropthorne, Eckington, and Bengeworth indicate a climate warmer than the present, and of the same age as the shells from No. 4 Terrace at Ailstone, probably also as those from Birlingham (No. 4) and Bricklehampton Bank (No. 3), but older than those found together with the Mammoth fauna in the lower No. 2 Terrace.

(e) No. 2 Terrace.—More deposits belong to No. 2 Terrace than to any other Avon river-terrace, as is shown in the map (Pl. X, fig. 1). Between Stratford and Tewkesbury they consist of sands and gravels usually rising from the alluvium by a marked feature in the form of a terrace-edge, 15 to 21 feet above the alluvium. The top of the terrace is almost flat, and in some places more than a mile wide. The light soil to which these deposits give rise and the general flatness of the surface make them suitable for market-gardening. There are several exposures showing beds of gravel and sand: in many cases, the sand is remarkably clean and sharp. A typical exposure is to be seen in a gravel-pit at Offenham, north of Evesham, where the following section was noted:—

.5	Thickness in	feet	inches
Soil with pebbles		3	. 0
Yellow sand		0	7
Gravel, with seams of red clay		3	0
Fine silver-sand		0	7
Gravel		3	0
Yellow sand		0	7
Blue clay (Lias?).			

The gravel contains many rounded Bunter pebbles (of quartz, quartzite, black chert, etc.), also many yellow flints, with much Jurassic detritus, including oolitic limestone, waterworn Gryphaa, belemnites, ammonites, stems of Pentacrinus, and valves of Cardinia and Rhynchonella: these fossils are much waterworn.

Frequently many small pellets of ironstone are found.

Near Stratford-on-Avon are large stretches of No. 2 Terrace. One pit, about 100 yards from Stratford Bridge along the Tiddington Road, has yielded a molar of Rhinoceros tichorinus and a fragment of molar of Elephus primigenius. Several molars of Mammoth have been obtained from similar gravels near Shottery. Part of an antler of Reindeer, identified by the late Dr. C. W. Andrews, came out of a sewer in the Evesham Road. I obtained an almost spherical flint-ball from a pit near the Sewage Farm, and two from the pit near Tiddington Road. Reference will be made to these in the sequel (p. 154).

Big stretches of No. 2 Terrace occur near Welford. There is an interesting exposure overlooking the Avon near Welford Pastures: the top of the pit is 25 feet above the river. The deposit is mostly sand and line gravel, of which from 8 to 9 feet were exposed. In the sand were seams of gravel and lenticles of loam. Several

freshwater shells were found in the sand, but a greater number came from a lenticle of loam about 4 feet below the top of the exposure.

A list of these shells will be found in § VII, p. 164.

Gravels of No. 2 Terrace are well developed near Bidford, where they occur in a shallow valley east of Marriage Hill, and stretch northwards from Bidford to the banks of the Arrow at Broom. This valley is about half a mile wide, and at present is drained by a very small brook. There are three exposures in this patch of gravels: two near Bidford and one near Broom. Of the Bidford exposures, one is a cutting immediately behind the Post Office. It was here that Mr. John Humphreys excavated a pre-Christian burial site in the summers of 1922 and 1923. The bodies were found buried in drift at a depth of $2\frac{1}{2}$ feet. Below this depth, in undisturbed gravel, Mr. Humphreys obtained two fresh flint-flakes, one of which Mr. Reginald Smith considered to be of Mousterian type. Three spherical flints, similar to those found at Stratford, were also obtained.

The other Bidford exposure is situated in a large gravel-pit at the eastern foot of Marriage Hill, where 10 feet of sand and gravel were exposed, resting upon dark-red marl (Keuper) about 15 feet below

the surface, or a few feet above the top of the alluvium.

The pit at Broom is situated near the left bank of the Arrow. About 16 feet of sand and gravel are exposed. Two different deposits seem to be present in this pit. At the top is red gravel containing Bunter pebbles and a few flints. At the base is a curved bed of red loam, and below this about 4 feet of yellow sand and gravel containing many ironstone pellets, a few freshwater shells (see § VII), flints, and Bunter pebbles. The lower yellow sand and gravel differ from the overlying red gravel in the large amount of ironstone which the lower deposits contain.

A few hundred yards up the Arrow, near Broom Mill, is a small pit containing 8 feet of gravel, the whole of which was similar to the upper gravel of the Broom pit. No Jurassic material was noted, but Bunter pebbles and a large angular piece of Welsh volcanic ash

were present.

It seems as if the upper red gravel of the Broom pit was deposited by the Arrow, and the lower yellow part (with its Jurassic material) by the Avon. In any case, the presence of the gravel-filled valley (map, Pl. X, fig. 1) which lies east of Marriage Hill, between the Avon at Bidford and the Arrow at Broom, suggests that the Avon once flowed through this valley round the northern end of Marriage Hill. About 5 feet below the top of the Broom pit, an extremely decayed fragment of an incisor of *Hippopotamus* was found by Mr. C. W. K. Wallis, of Edgbaston. It is in very fragile condition, and, if we may judge from its appearance, there is very little doubt that it was derived from some older deposit.

In the bend of the river near Offenham occurs a large patch of these gravels, giving rise to many acres of good market-gardens. The pit at Offenham which was described as a type-section of the deposits of No. 2 Terrace (p. 150) is situated on the left of the lane leading to Offenham Ferry, and the top of it is about 15 feet above the alluvium. Freshwater shells (see § VII) and mammalian remains have been obtained from this pit. The latter, now in the possession of Mr. R. Webl-, of Evesham, consist of a molar of Elephas primigenius, several molars of Rhinoceros tichorhinus, and a tibia and jaw of Equus. From Evesham to Tewkesbury, deposits of No. 2 Terrace occur, with very few breaks. They attain their greatest width between Evesham and Pershore, where they frequently exceed a mile in width.

In a pit in the yard of Chadbury Farm, a thickness of some 10 feet of gravel and sand is exposed. Three valves of freshwater shells (see §VII) were obtained about 9 feet from the surface,

and only a few feet above the level of the alluvium.

A large, flat, sandy stretch occurs between Fladbury and Wyre. The sites of many old gravel-pits are now overgrown in this district. Strickland (1, p. 99) states that, between Moor and Wyre, on a platform 25 feet above the river and distant 100 yards from the river, freshwater shells were found. Remains of Mammoth, Cervus dama, Reindeer, Rhinoceros, and Bison from Fladbury, now in the Worcester Museum, probably came from these pits.

Pershore and Pensham stand on deposits of No. 2 Terrace, but

no fossils have been recorded from these localities.

The next record comes from No. 2 Terrace at Defford. After referring to the bones and shells found at Eckington (No. 3 Terrace described above), Strickland says (2, p. 142) that on the opposite bank of the Avon, about 20 feet above the river, bones of Mammoth, Rhinoceros tichorhinus, and Hyæna spelæa occur beneath the gravel. This agrees in position with No. 2 Terrace at Defford.

I can trace no record of fossils found in this terrace between Defford and Tewkesbury, and there are very few exposures at the present time.

From the preceding account of the deposits of No. 2 Terrace it will be seen that they form the greater part of the Avon rivergravels, and contain the largest number of contemporary fossils. The following is a list of mammalian remains and freshwater shells from No. 2 Terrace. They constitute an assemblage indicative of a colder climate than that of the present day, or than that of No. 3 Terrace or No. 4 Terrace. The only evidence of human industry so far discovered is the single implement of Mousterian type found at Bidford (p. 151).

MAMMALIAN REMAINS OCCURRING IN No. 2 TERRACE.

Elephas primigenius. Common. Rhinoceros tichorhinus. Common. Bison sp. Bos sp. Equus sp.
Cervus dama.
Cervus tarandus.
Hyæna spelæa.

FRESHWATER SHELLS.

Sphærium corneum.
Pisidium amnicum.
Pisidium cinereum.
Pisidium nitidum.
Pisidium pusillulum.
Pisidium personatum.
Pisidium henslowanum.
Succinea pfeifferi.

Succinea oblonga. Pupilla muscorum. Limnæa palustris. Limnæa pereger. Limnæa truncatula. Planorbis lævis. Unio (sp.). Valvata piscinalis.

(f) No. 1 Terrace.—There are indications of a lower level of drift rising never more than 10 feet above the alluvium. Such low areas are shown on the map (Pl. X, fig. 1) as No. 1 Terrace: it takes the form of low, nearly flat land. Occasionally, a sharp rise of 2 or 3 feet makes a small feature between the alluvium and No. 1 Terrace. Where No. 2 Terrace is present, No. 1 is separated from it by a sudden terrace-like slope about 10 feet high. There are no good exposures, but molehills in the fields show a fine reddish sand quite distinct from the alluvium.

Near Bidford an old exposure, partly filled with rubbish, showed from 3 to 4 feet of fine, red, sandy earth. In the Worcester Meadows near Salford Priors, quite close to the Avon, is an 'island' of red sand rising 6 to 7 feet above the alluvium which

surrounds it.

It seems probable that deposits of No. 1 Terrace extend below the alluvium, but there is no definite proof of this. Near Fladbury Mill, not far from a stretch of No. 1 Terrace, there was a boring through the alluvium, of which the following record was given by Mr. Louis Barrow, of King's Norton, to Dr. L. J. Wills:—

	Thickness in	feet.
Alluvial brown silt		18
Bright blue Lias (?) marl, with occasion		
flints about 4 feet down)		
Orange-coloured gravel T	hickness not sta	ted.

In the absence of more detail it is impossible to connect this boring with the deposits of No. 1 Terrace, although such a connexion is not unlikely, especially since there is evidence of a sunken channel extending below the alluvium in the valley of the Severn at Tewkesbury (9, p. 37).

No contemporary fossils have been recorded from No. 1 Terrace

in the Avon Valley.

Other gravels, which are not shown on the map (Pl. X, fig. 1), occur round the base of Bredon Hill. These appear to belong to a suite of deposits different from those composing the river-terraces, in that they consist for the greater part of subangular fragments of Jurassic débris, with a marked absence of flints and Bunter pebbles. It seems, therefore, advisable to postpone the discussion of these gravels and their relation to the Avon river-terraces, until further investigations have been made in the neighbourhood of the Cotswold Hills.

III. MATERIALS OF THE FLUVIATILE GRAVELS.

The same assemblage of materials characterizes all the Avon The main constituents are large quantities of Jurassic detritus, flints from the Cretaceous rocks, and Bunter pebbles. The Jurassic material includes waterworn fossils, such as Gryphæa incurva, belemnites, stems of Pentacrinus, valves of Cardinia, and fragments of ammonites. Nearly all the gravels, especially the fine varieties, contain large quantities of small ironstone-pellets. Numerous flints occur everywhere; usually much chipped, and sometimes wind-polished. Up to the present time none have been found showing undoubted human workmanship, except the specimen recorded from Bidford. In several localities almost symmetrically rounded flints have been obtained. Some of these flint-balls are smooth, and some curiously bruised, as if with much battering. They bear a marked resemblance to the spherical flints of the Cannonshot Gravel of Norfolk, from which they may be derived. It is probable that the Jurassic and Cretaceous material in the Avon gravels is of eastern origin. It occurs in quantities so great in the river-deposits as far north as Rugby, that it seems likely that some powerful denuding agents, such as were at work during a glacial epoch, were the main factors in its original accumulation. In addition to the eastern material we find innumerable Bunter pebbles, probably derived from the Bunter Pebble-Bed of the Birmingham district.

In Terrace No. 2, near Stratford, occurred an angular piece of volcanic ash, probably of Welsh origin. This may have come down one of the north-western tributaries draining from the area round Birmingham once occupied by the Welsh ice-sheet. The Arrow tributary river-deposits, which have been examined by

Dr. L. J. Wills, frequently contain Welsh material.

IV. Suggested Interpretation of the Avon Valley-Gravels.

(a) Discussion of Difficulties.

There are five main levels at which river-deposits occur in the Avon Valley, yet there are many difficulties in attempting to establish a relationship between the five terraces. Any just interpretation should combine lithological, stratigraphical, and palæontological evidence. In the Avon Valley there is no marked change in the materials that compose the several terraces, although, as a rule, the deposits of No. 2 Terrace are much less closely cemented than those of the higher levels. As regards the palæontological evidence in the Avon river-deposits, fossils occur at No. 4, No. 3, and No. 2 levels; but reliable records of mammalian remains are limited to No. 3 and No. 2. The fauna of No. 2 is a 'cold' fauna, with numerous remains of Mammoth and Rhinoceros tichorhinus; No. 3 contains Hippopotamus and 'warm-climate' shells; and

No. 4 has yielded 'warm-climate' shells in two localities. No. 5 and No. I have yielded no fossils. Palæontological evidence of itself appears, in the light of present-day knowledge, to be insufficient to establish the relative age of the gravels; for, although the Hippopotamus-Corbicula fauna has usually been regarded as older than that of the Mammoth and the Woolly Rhinoceros, there are cases where these 'warm' and 'cold' faunas have been shown to alternate more than once. Thus, the Hippopotamus-Corbicula fauna is considered older than gravels containing Mammoth and Rhinoceros tichorhinus in the Cam (11, p. 228-29) and the Somme (12, p. 27); but is stated to be later than the gravels containing Mammoth in the Upper Thames (13, p. 68). The application of paleontological methods to the elucidation of the Avon gravels is made still more difficult by the almost complete absence of flint-implements in the river-deposits. This cultural evidence, which plays an important part in the interpretation of the gravels of the Cam, the Somme, and the Thames, gives no help in interpreting the fluviatile deposits in the Avon Valley.

However, by combining the stratigraphical and paleontological evidence so far available, it seems to be possible to arrive at certain conclusions with regard to the relationship of these deposits.

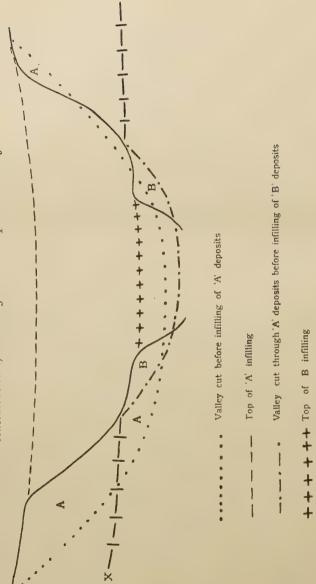
(b) Reasons for Classifying Fluviatile Deposits according to their Maximum Surface-Height above the River.

It is clearly shown in the gradient-diagram (Pl. X, fig. 2) that, when traced for some distance, the lines through the upper surfaces of the deposits of each terrace give five curves roughly parallel to the present thalweg of the Avon, each very suggestive of a river-gradient. The lines through their bases are more irregular. There seems to be evidence that there have been stages in the history of the Avon when the river cut a deep valley, followed by a period when this valley was filled in with sediments

to a depth of 50 feet or more (pp. 140, 143).

If one considers the re-excavation of a valley through such an infilling, and the subsequent filling-up of this later valley, it is possible to demonstrate considerable variation in the heights above the river of the bases of deposits belonging to the same period of aggradation, while the maximum surface-heights in each terrace, despite erosion, will maintain approximately the same level above the present thalweg. The diagram (fig. 4, p. 156) illustrates this point. A deep valley is nearly filled with 'A' deposits, and through these a new valley is cut and subsequently filled in part with 'B' deposits. On the left of the diagram 'A' deposits extend down the side of the valley, below the level of the top of 'B' deposits; while on the right 'A' deposits are separated from B' deposits by a slope of solid rock. Thus the base of 'A' deposits may be found at any height between the bottom and the top of the 'A' infilling, and it is only when gravels corresponding to the same stage of infilling are left on the side of the valley that

Fig. 4.—Diagram showing that the relative ages of river-gravels cannot always be deduced from a consideration of their height above the present thalweg.



X-|-| - Y Surface to which valley sides may have been

subsequently denuded

a line through their bases represents a curve parallel to the thalweg of the valley which contained them. On the other hand, even when the surface of the gravel has been considerably denuded, the line through the highest parts preserved will represent a curve subparallel to the thalweg of the valley which contained it. For this reason, the Avon gravels have not been classified according to the height of their base, but rather according to the maximum height to which they rise above the surface.

(c) Evidence of Big Excavations followed by Big Infillings in the Avon Valley.

The diagram (fig. 4, p. 156) serves to illustrate another point—that the relative age of gravels cannot always be deduced from a consideration of their height above the river, as was suggested by Prof. J. E. Marr (17, p. 67). Deposits occurring at the top of 'A' infilling are slightly more recent than 'A' gravels at the base of the same infilling, and approximately the same height above the river as 'B' gravels. If subsequent excavation had lowered the sides of the valley to the line of XY in the diagram, beds of two different ages would occur, with surfaces at almost the same

level in the valley (see p. 145).

It seems probable that deep valleys have been cut, and then filled with sediments to a considerable depth, at least twice in the history of the Avon. Evidence has been discussed (p. 140) to show that at Strensham the valley had probably been cut to at least the level of the top of No. 4 Terrace (90 feet above the river) followed by an infilling of over 40 feet of sediments forming No. 5 Terrace. A depth of more than 40 feet of gravel on Welford Hill (p. 140) is also suggestive of such an infilling. These two remnants must have been near the centre of the old valley, and thus show a great thickness of deposits. In other cases, where the gravels are comparatively thin, they probably represent the last part of the infilling, preserved towards the sides of the old valley.

Another deep excavation seems to have taken place to about 40 feet above the present river. Later, this valley became the scene of aggradation, and there were laid down river-deposits to a depth of 50 feet. It is the last part of this infilling that is designated No. 4 Terrace (about 80 to 90 feet above the river). The evidence of deep excavation is found at Cropthorne, Luddington, and in the Stratford district, where gravels appear to extend from No. 4 level to a height of about 40 feet above the river. It seems probable, therefore, that at these places the infilling of the central part of the valley has been preserved. Elsewhere, all that remains of

¹ Except where lateral streams have effected much erosion, it is probable that the surface of each remnant of a terrace will have suffered approximately the same amount of erosion.

it is the deposits of No. 4 Terrace which originally lay to the side of the old valley, and now rest upon solid rock at 60 to 70 feet above the river (note the deposits on the right of the diagram, fig. 4, p. 156).

Since this downward extension of the gravels from No. 4 level to within 40 feet of the present river includes No. 3 level, it becomes necessary to consider the relationship of No. 3 Terrace

deposits to those of No. 4 & No. 2 Terraces.

(d) Relationship of No. 3 Terrace to No. 2 Terrace.

A series of sands and gravels (No. 3 Terrace) occur with their surfaces about 40 to 50 feet above the river, or only about 10 feet above the top of No. 2 Terrace. In most cases these deposits have a terrace-like surface, and it is from such alone that remains of contemporary *Hippopotamus* have been obtained. But in the Cropthorne, Luddington, and Stratford districts, as mentioned above, gravels at this level appear to be the downward extension of No. 4 Terrace.

With regard to the associated molluscan fauna, except for the Littleworth Street, Evesham, shells (p. 148), which are very few in number, poor in species, and dwarfed, Mr. A. S. Kennard & Mr. B. B. Woodward (§ VII) consider that the shells from localities in No. 3 Terrace lived in a climate warmer than that of the present day, and are probably older than those occurring with

the 'cold' Mammoth fauna in No. 2 Terrace.

Now, the existence at similar levels above the present Avon (30 to 40 feet) of Hippopotamus-remains, associated perhaps with Elephas antiquus, and certainly with warmer-climate shells (including Belgrandia marginata and Unio littoralis), seems to be very significant. Hippopotamus-remains occur with Corbicula fluminalis, Belgrandia marginata, and Unio littoralis, together with Chellean implements, in the Cam Valley (11, p. 210), in gravels, from 25 to 40 feet above sea-level, that are considered to be older than those containing the 'cold' Mammoth fauna and Upper Palæolithic implements. In the Somme region, deposits containing Hippopotamus are sometimes found to underlie those containing the Mammoth fauna (12, p. 27) in the lowest or 10-metre terrace. In one case Commont says that, near Montières and St. Roch, the 10-metre terrace contains Elephas antiquus and Hippopotamus associated with Chellean industry, up to 20 metres O.D.; but nearer the river, at 18:16 metres, the gravels furnished Elephas primigenius, Rhinoceros tichorhinus, and Levallois flakes (14, p. 194, footnote). This is strikingly analogous to the conditions noted in the Avon Valley, where the gravels containing Hippopotamus (No. 3 Terrace) occur at a surface-height of about 10 feet above the maximum height of Terrace No. 2, which contains a 'cold' Mammoth fauna. In both the Cam and the Somme areas, the Hippopotamus gravels are regarded as earlier than the terrace-gravels containing Elephas

primigenius and Rhinoceros tichorhinus.

According to the views expressed by the officers of H.M. Geological Survey (15, p. 48), the two faunas occur mixed in the Lower Thames valley; although Mr. S. H. Warren (16, p. 607) states that, at Grays, the two faunas occur in separate deposits at the same level,

'the earlier (Little Thurrock) group consists of the classical Corbicula and Hippopotamus beds; while the basement-gravel of the later group (West Thurrock) yields an abundant proto-Mousterian industry..., and is closely succeeded in the overlying beds by the Elephas-primigenius fauna.'

But, on the other hand, Dr. K. S. Sandford (13, p. 68) records gravels containing *Hippopotamus* and *Corbicula*, resting upon beds containing *Elephas primigenius* and *Rhinoceros tichorhinus*, in his Summertown-Radley Terrace, with a base 20 feet above the Thames near Oxford.

In the Warwickshire Avon there is no evidence, up to the present, to suggest that the *Hippopotamus* Beds of Terrace No. 3 are more recent than those characterized by Mammoth. They always occur at a level distinctly higher than that of No. 2 Terrace, and have nowhere been seen to overlie that terrace. Thus, there seems no reason to regard No. 3 Terrace as more recent than No. 2 in this district, but rather as a deposit analogous with the *Hippopotamus* Beds of the Cam and the Somme.

If this be so, it seems probable that in the Avon Valley, as in the Somme and the Cam Valleys, there is evidence of a deep excavation of the valley before these *Hippopotamus* Beds were deposited. In the case of the Avon, this excavation was carried

down to at least 30 or 40 feet above the present alluvium.

(e) Relationship of No. 3 Terrace to No. 4 Terrace.

After this deep excavation there followed, apparently, an infilling of the valley with sediments to the top of No. 4 Terrace (that is, 50 feet or more; see p. 143). This infilling includes gravels at No. 3 level, and thus it seems probable that No. 3 Terrace deposits represent the lower part of the infilling, while gravels at No. 4 level are the upper part of the same filling-up of the valley. This intimate connexion between No. 3 and No. 4 Terrace deposits is also suggested by the fact that two collections of 'warmclimate' shells, one including Corbicula fluminalis and Unio littoralis, have been obtained from No. 4 level (p. 143). These shells are considered to be of about the same age as those associated with Hippopotamus from New Inn, Cropthorne, at No. 3 level. Thus, both the stratigraphical and the palæontological evidence seem to indicate that No. 3 and No. 4 Terrace deposits belong to the same period of aggradation. If this be the case, there was probably a pause in the subsequent excavation, during which the terrace-like tops of some of No. 3 Terrace deposits were formed.

As an alternative theory, one might regard No. 3 Terrace deposits with terrace-like tops and containing a Hippopotamus fauna as banked against No. 4 Terrace deposits, in which case they are

younger than those of No. 4 Terrace.

In either case, the evidence from the Rector's Pit, Cropthorne (see p. 143), implies necessarily a deep excavation of the valley before No. 4 gravels (50 feet at Cropthorne) were laid down. So far as present evidence goes, both theories as to the age of No. 3 Terrace deposits are possibilities; but the fact that shells from No. 4 and No. 3 levels indicate a similar climate and age appears to give a balance in favour of the first hypothesis: namely, that No. 3 Terrace deposits are older than those of No. 4 Terrace, and represent the first part of the infilling of a deep valley, also that No. 4 deposits represent the final stage.

(f) No. 2 Terrace.

Perhaps the most striking fact to be noticed in the gradientdiagram (Pl. X, fig. 2) is the uniformity shown in the heights above the river of the gravels of No. 2 Terrace. The tops of these deposits have probably suffered little denudation, and, when traced down the river, give a curve parallel to the alluvial plain of the period which they represent. The fossils from No. 2 Terrace include abundant remains of Mammoth and Rhinoceros tichorhinus, as also freshwater shells. Probably all the collections of shells from the six localities at No. 2 level indicate a climate colder than that of the present day, and are of later age than those obtained from exposures in No. 3 or No. 4 Terrace. The only undoubted human implement obtained from the Avon gravels is of Mousterian type, from No. 2 Terrace at Bidford.

From both stratigraphical and paleontological evidence, the deposits of No. 2 Terrace appear to belong to a later period than

those containing the Hippopotamus fauna.

(g) No. 1 Terrace.

Only a few areas of No. 1 Terrace have been mapped. It has furnished no fossils, and is poorly exposed: its position only slightly above the alluvium, through which it sometimes appears like an 'island', suggests its recent date. No. 1 Terrace may possibly be connected with deposits underlying the alluvium. The existence of such deposits has been proved only near Fladbury in the Avon Valley, but it is not unlikely that a buried channel exists elsewhere, since alluvial deposits have been shown to extend 40 feet below the river-level at Tewkesbury. At present, there is no conclusive evidence that No. 1 Terrace is connected with such a buried channel.

(h) Summary of Stages in the History of the Avon Valley.

So far as present evidence goes, the history of events in the Avon Valley appears to have been somewhat as follows:—

(1) Excavation of the valley through fluvioglacial drifts and solid rock to about 90 feet above the present alluvium.

(2) Aggradation of about 50 feet-No. 5 Terrace deposits.

- (3) Excavation at least to the level of the top of No. 2 Terrace: that is, to about 30 or 40 feet above the alluvium.
- (4) Aggradation of about 60 feet = gravels of No. 3 and No. 4 Terraces containing a 'warm-climate' fauna (Hippopotamus, Corbicula fluminalis).
- (5) Excavations to about 40 or 50 feet above the present river, when the terrace-like tops of some of No. 3 Terrace deposits may have been formed

(6) Renewed excavation to a few feet above the present alluvium.

(7) Aggradation of about 30 feet = gravels of No. 2 Terrace containing a 'cold-climate' fauna (Mammoth, Rhinoceros tichorhinus).

(8) Excavation of unknown depth, followed by the deposition of No. 1
Terrace.

V. Points of Comparison with other River-Valleys.

At this stage, it is not possible to attempt a complete correlation between the Avon river-deposits and the fluviatile deposits of other river-basins; but it is of interest to point out a few apparent similarities. Fig. 5 (p. 162) is an attempt to illustrate diagrammatically the history of the valley of the Somme as interpreted by Lamothe (12), of the Cam according to Marr (11), and the Avon. Aggradation is represented by continuous lines and excavation by broken lines. There is a general resemblance between the three diagrams, the most important points being:—

(1) The order and magnitude of events which have taken place in each

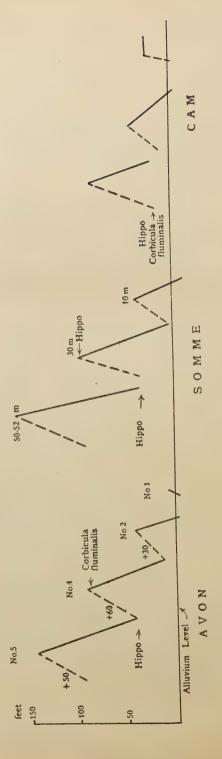
of the valleys are very similar.

(2) There is evidence that a deep excavation has taken place at the same stage in the history of each valley, followed by a big infilling, at the beginning of which beds containing the 'warm-climate' Hippopotamus fauna were laid down.

(3) In the case of each river, a valley containing the 'cold-climate' Mammoth fauna was excavated through the infilling containing the Hippopotamus fauna. There appears to be no evidence in these valleys that it was followed by the return of a Hippopotamus fauna.

On the other hand, it must be noted that the top of the deep infilling (30-metre Terrace) in the Somme Valley has yielded a Hippopotamus fauna with Chellean implements; whereas, in the Cam Valley round Cambridge (Observatory Beds, 11, p. 219), the corresponding deposits contain Mousterian implements at the top, and probably overlie beds containing Chellean implements. These beds appear to have yielded no fauna. In the Avon, No. 4 Terrace, representing the last stages of infilling, has yielded 'warm-climate' shells, including Corbicula fluminalis and Unio

Fig. 5.—Diagram showing the magnitude and order of the stages in the development of the present valley of the Avon: also the Somme (after Lamothe) and the Cam (after Marr).



littoralis; but there are no reliable records of mammalian remains.

No attempt has been made to correlate the Avon terraces with those of the Lower Thames, on account of the apparent mixing of the faunas in the latter valley; on account, also, of the absence of sufficiently definite evidence of periods of excavation alternating with aggradation on a scale comparable with the other valleys.

In conclusion, I wish to acknowledge my indebtedness to Mr. John Humphreys, F.S.A., F.G.S., for identifying mammalian teeth; to Mr. A. S. Kennard, A.L.S., F.G.S., & Mr. B. B. Woodward, F.L.S., F.G.S., for identifying freshwater shells and furnishing an Appendix to this paper (§ VII); and to Dr. L. J. Wills, who suggested the work, and to whose help the greater part of it is due.

VI. BIBLIOGRAPHY.

- STRICKLAND, H. E.—'On the Deposits of Transported Materials usually termed Drift, which exist in the Counties of Worcester & Warwick' Jardine's Memoirs of H. E. Strickland, 1858, p. 90.
 2. 1d.—'Sections on the Birmingham & Gloucester Railway' op. cit. p. 132.

- LLOYD, T. G. B.—'On the Superficial Deposits of Portions of the Avon & Severn Valleys & Adjoining Districts' Q. J. G. S. vol. xxvi (1870) p. 202.
 LUCY, W. C.—'The Gravels of the Severn, Avon, Evenlode, & their Extension over the Cotteswold Hills' Proc. Cotteswold Nat. F.-C. vol. v (1869)
- p. 71.

 5. Grax, J. W.—'Notes on the Cotswold-Malvern Region' Proc. Cotteswold Nat. F.-C. vol. xx (1919) p. 99.

 Nat. F.-C. vol. xx (1919) p. 99.

- Nat. F.-C. vol. xx (1919) p. 99.

 6. Wilson, J. M.—'On the Surface-Deposits in the Neighbourhood of Rugby' Q. J. G. S. vol. xxvi (1870) p. 192.

 7. Winnington-Ingram, A. H.—'Superficial Deposits in the Neighbourhood of Evesham' Q. J. G. S. vol. xxxv (1879) p. 678.

 8. Murchison. Sir Roderick.—'The Silurian System' 1839, p. 556.

 9. Symonds, W. S.—'On the Drifts of the Severn, Avon, Wye, & Usk' Proc. Cotteswold Nat. F.-C. vol. iii (1861) pp. 31-39.

 10. Osboen, H. F.—'The Age of Mammals' 1910.

 11. Marr, J. E.—'The Pleistocene Deposits round Cambridge' Q. J. G. S. vol. 1878 (1910) p. 204.
- lxxv (1919) p. 204.
- DE LAMOTHE, P.—'Les Ancienne Nappes Alluviales & Lignes de Rivage du Bassin de la Somme, & leurs Rapports avec celles de la Méditerranée Occidentale' Bull. Soc. Géol. France, ser. 4, vol xviii (1918) p. 3.
 SANDFOED, K. S.—'The Fossil Elephants of the Upper Thames Basin' Abs.
- Proc. Geol. Soc., April 3rd, 1924, p. 68.

 14. Commont, V.—'Terrasses Fluviatiles de la Vallée de la Somme' Ann. Soc. Géol. Nord, vol. xxxix (1910) p. 185.

 15. Dewey, H., & Beomehead, C. E. N.—Mem. Geol. Surv. England & Wales (South London, 1921).
- 16. WARREN, S. H.—'The Elephas-antiquus Bed of Clacton-on-Sea (Essex), & its
- Flora & Fauna 'Q. J. G. S. vol. lxxix (1923) p. 606.

 17. MARE, J. E.—'On Submergence & Glacial Climates during the Accumulation of the Cambridgeshire Pleistocene Deposits' Proc. Cambridge Phil. Soc. vol. xix (1916-19) p. 64.

VII. The Pleistocene Non-Marine Mollusca of the Avon Valley. By Alfred Santer Kennard, A.L.S., F.G.S., & Bernard Barham Woodward, F.L.S., F.G.S.

The most important paper on the Pleistocene deposits of the Avon Valley is by H. E. Strickland. This was sent to the Geological Society in June, 1835, and a brief abstract was published; but the paper was first printed in full in 1858.²

As Jardine states, 'most of the localities mentioned are now either filled up, worked out, or become otherwise inaccessible,' and it is a matter of congratulation that so careful and competent an observer as Strickland was a resident in the district, while it is noteworthy that but little has been added to our knowledge since. It is, however, necessary to bring our knowledge up to date, and we thank Miss Tomlinson for submitting her specimens for examination; we also thank Mr. W. H. Edwards of the Victoria Institute, Worcester, for similar courtesy, and Mr. Hugh Watson for assistance with the Strickland Collection now preserved at Cambridge.

Ailstone.

Fourteen species were obtained from this locality, namely:—

Pupilla muscorum (Linné). 3 ex-

amples.

Limnæa pereger (Müller). Common.

Limnæa truncatula (Müller). 2 examples.

Planorbis lævis Alder. 2 examples.

Ancylastrum fluviatile (Müller). 2
examples.

Valvata piscinalis (Müller). 2 ex-

Bithynia tentaculata (Linné). 1 example.

Unio littoralis Cuvier. 1 valve. Corbicula fluminalis (Müller).

valves. Sphærium corneum (Linné). Com-

Pisidium amnicum (Müller). Com-

Pisidium cinereum Alder. Common. Pisidium henslowanum (Sheppard). Common.

Pisidium subtruncatum Malm. 1 valve.

All the examples of *Corbicula fluminalis* are broken, showing that they are drifted shells. This is the first record of the species from the Midlands, and shows that this form was not restricted to the Thames-Rhine river-system, an important fact. The deposit is clearly of Middle or Early Pleistocene age, probably the former, and it may well be older than the Cropthorne beds.

Bengeworth.

Strickland (Memoirs, p. 94) states that examples of *Unio ovalis* occurred in clay at Bengeworth, a statement that was repeated in 1879 by the Rev. A. H. Winnington-Ingram.³ A valve of *Unio* from this locality is preserved in the British Museum

³ Q. J. G. S. vol. xxxv, p. 678.

¹ Proc. Geol. Soc. vol. ii, pp. 95 & 111.

² Sir William Jardine, 'Memoirs of H. E. Strickland' pp. 90-104.

(Natural History). We cannot identify it with any described species, but do not consider it advisable to describe it until further material comes to hand.

Birlingham.

A short account of this deposit and the contained mollusca was given in 1854 by P. P. Carpenter. The shells were found at a depth of 20 feet in sinking a well, and there is a series in the Victoria Institute, Worcester. Seventeen species are represented, namely:—

Pupilla muscorum (Linné).
Succinea sp.
Ancylastrum fluviatile (Müller).
Limnæa pereger (Müller).
Limnæa truncatula (Müller).
Planorbis crista (Linné).
Planorbis lævis Alder.
Planorbis leucostoma Millet,
Bithynia tentaculata (Linné).

Valvata piscinalis (Müller).
Sphærium corneum (Linné).
Pisidium amnicum (Müller).
Pisidium henslowanum (Sheppard).
Pisidium supinum A. Schmidt.
Pisidium subtruncatum Malm.
Pisidium cinereum Alder.
Pisidium pusillulum B. B. Woodward.

A few small derivative marine shells were also present. P. P. Carpenter recorded *Myxas* [Linnæa] glutinosa (Müller); but probably an example of Linnæa pereger (Müller) was mistaken for it.

Bricktehampton Bank.

Strickland noted that shells of the same species as those found at Cropthorne had been collected in a gravel-pit and a brick-yard at Bricklehampton Bank, about half a mile west of Cropthorne,² and a small series is preserved in the Victoria Institute, Worcester. Six species are represented, namely:—

Valvata piscinalis (Müller). Sphærium corneum (Linné). Pisidium supinum A. Schmidt. Pisidium cinereum Alder. Pisidium nitidum Jenyns.
Pisidium pusillulum B. B. Woodward.

This series gives practically no clue as to the age of the deposit, except that it cannot be early Pleistocene.

Broom.

Miss Tomlinson collected a small series in a gravel-pit at Broom, but only three species were present, namely:—

Sphærium corneum (Linné). One valve.
Pisidium amnicum (Müller). One

Pisidium cinereum Alder. Two valves.

These shells furnish no clue as to the age of the deposit.

Chadbury.

Only two species were obtained from the gravel of this locality, namely:—Succinea pfeifferi Rossmässler and Pisidium sp. Here again there is no clue as to age.

¹ Rep. Brit. Assoc. 1854, p. 78.

² 'Memoirs, &c.' 1858, p. 98.

Cropthorne.

As already noted, Strickland's paper describing this deposit, with a list of the shells and descriptions of the three supposed new species, was not published until 18581; but the list of the species was printed in Murchison's 'Siluria' (1839, p. 355), and this was the origin of the numerous Cropthorne references occurring in the literature of the ensuing twenty years. A letter from Strickland to James Smith of Jordanhill, dated February 18th, 1839, was published in 1862: it contains descriptions of the three supposed new species, with more details than those given in the paper.²

We have been able to examine four extant series, one in the Victoria Institute, Worcester, given by Mrs. Strickland; one in the Museum of Practical Geology, Jermyn Street, given by Strickland to the Geological Society; a small series in the Prestwich Collection, British Museum (Natural History); and Strickland's own collection, now at Cambridge. From these sources we are

able to compile a list of thirty species, namely:-

Limax arborum Bouchard-Chantereux,

Cernuella virgata (Da Costa). Vallonia pulchella (Müller). Vallonia excentrica Sterki. Pupilla muscorum (Linné).

S Vertigo pygmæa (Draparnaud). Succinea pfeifferi Rossmässler. S Ancylastrum fluviatile (Müller).

Ancylus lacustris (Linné).

S Limnæa auricularia (Linné).
Limnæa palustris (Müller).
Limnæa pereger (Müller).
Limnæa truncatula (Müller).
Planorbis crista (Linné).
Planorbis lævis Alder.

Planorbis planorbis (Linné).
Planorbis vortex (Linné).
Belgrandia marginata (Michaud).
Bithynia tentaculata (Linné).
Valvata cristata Müller.
Valvata piscinalis (Müller).
Unio littoralis Cuvier.
Unio pictorum (Linné).
Unio tumidus Retzius.
Sphærium corneum (Linné).
Pisidium amnicum (Müller).

Planorbis leucostoma Millet.

Pisidium cinereum Alder. Pisidium henslowanum (Sheppard). Pisidium supinum A. Schmidt.

S=on the authority of H. E. Strickland, no extant specimens being known.

As already noted, Strickland described three species as new: Paludina minuta, Planorbis lateralis, and Unio antiquior (op. cit. pp. 97 & 98). The first is Belgrandia marginata (Michaud); the second Planorbis lævis Alder; while the last is a variety of Unio littoralis Cuvier.

Defford.

Strickland stated, on the authority of the workmen, that shells occurred in a gravel-pit south of this village, the bed being 20 feet above the Avon and 100 yards distant; he added that the shells occurred only at the base of the gravel, and that, owing to the water-level, he did not obtain any.³ The only examples that we

¹ 'Memoirs, &c.' pp. 95-98.

² 'Researches in Newer Pliocene & Post-Tertiary Geology' pp. 150-51.

³ 'Memoirs, &c.' pp. 99 & 142.

have seen are in the Prestwich Collection, British Museum (Natural History), and two species are represented, namely:—Pisidium cinereum Alder and P. pusillulum B. B. Woodward, and these furnish no evidence as to age.

Eckington.

The occurrence of shells and bones in the railway-cutting north of Eckington is also noted by Strickland. He states that they occurred about 35 feet above the Avon, and that the most abundant species were *Sphærium* [Cyclas] corneum (Linné) and Pisidium [Cyclas] amnicum (Müller). We have seen no examples from this deposit.

Evesham.

The Rev. A. H. Winnington-Ingram states,

'On the opposite bank of the river, at Evesham, about a quarter of a mile from its modern course, occurs a formation of similar character and depth [to that of Bengeworth], and the clay there has contributed, in a well sunk through the sand interspersed with river-shells, an antler of a Reindeer' (Q. J. G. S. vol. xxxv, 1879, p. 678).

Miss Tomlinson sent us a series that she had obtained from a gravel-pit at Littleworth Street, Evesham. Six species are represented, namely:—

Limnæa pereger (Müller). Four examples.

Planorbis lævis Alder. Five ex-

Planorbis lævis Alder. Five examples.

Valvata piscinalis (Müller). Com-

Unio sp. Fragments.

Pisidium amnicum (Müller). Four valves.

Pisidium henslowanum (Sheppard). Common.

All the examples of *Valvata piscinalis* are dwarfed. Judging from the facies of these shells, this is a late Pleistocene deposit, the molluscan evidence thus confirming that furnished by the presence of the Reindeer.

Little Lawford.

Strickland has recorded four species from the Pleistocene gravel at this locality ('Memoirs' 1858, p. 94):—

Limnæa pereger (Müller). Unio sp. Pisidium amnicum (Müller). Pisidium henslowanum (Sheppard).

We have been unable to check these identifications.

Offenham.

Four species were obtained by Miss Tomlinson from this locality, namely:—

Pisidium cinereum Alder. Six valves.

Pisidium personatum Malm. Two valves.

Pisidium henslowanum (Sheppard).
One valve.

Pisidium nitidum Jenyns. One valve.

This is probably a late Pleistocene deposit.

¹ Op. cit. p. 141.

Welford Pasture.

Miss Tomlinson obtained nine species from the loam and sand at this locality, namely:—

Pupillamuscorum(Linné). Common. Succinea oblonga Draparnaud. Five examples.

Limnæa palustris (Müller). A fragment.

Limnæa pereger (Müller). Common.

Limnæa truncatula (Müller). Five examples.

Planorbis lævis Alder. Two examples.

The facies of these shells would indicate a rather late Pleistocene age.

With regard to the age of these deposits, it is a matter of regret that the evidence furnished by the mollusca is too often so slight that we cannot speak with certainty; but there would appear to be two well-marked horizons. The older, which is best characterized at ('ropthorne, indicates a climate warmer than that of the present day, and to this we would also assign the Eckington, Bengeworth, and Ailstone deposits, although there is a possibility that the last may be slightly the oldest. The newer series represents colder conditions, and includes Broom, Evesham, Offenham, and Welford Pasture.

In the remaining localities the evidence in our possession is not sufficient. It is probable, however, that Birlingham and Brickle-hampton Bank should be classed with Cropthorne; while Defford and Little Lawford may belong to the later stage. Comparing these with the Thames deposits, we may regard the older stage as probably of the same age as the Ilford (Uphall) deposits: that is, Middle Pleistocene; while the later stage is not far removed in time from the Ponder's End Arctic Bed, and is, therefore, late Pleistocene.

EXPLANATION OF PLATE X.

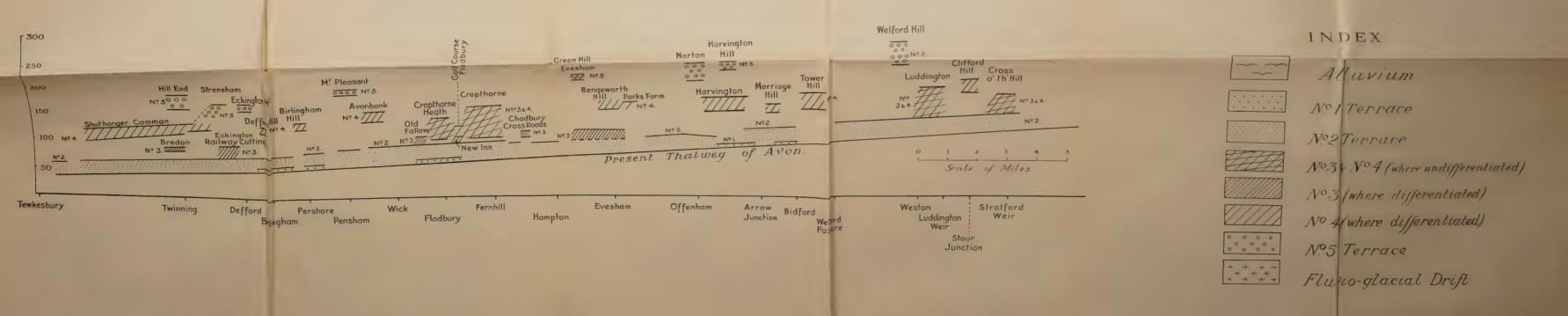
Fig. 1. Map illustrating the Pleistocene Deposits of the Lower Valley of the Warwickshire Avon, on the scale of 1 inch to the mile, or 1:63,360.
2. Section showing gradients of the Lower Avon river-terraces. Horizontal scale, 1 inch=2 miles, or 1:126,720.

DISCUSSION.

Prof. F. X. SCHAFFER remarked that the altitude of the highest terraces of the Avon and their agreement with those of the Somme recall the similar occurrences in Northern Africa, and in Southern and Central Europe. The cause has not yet been ascertained. The 50-metre terrace seems to be of Upper Pliocene age around the Mediterranean Basin. The most surprising phenomenon on the European continent is the accordance of the relative altitudes of the terraces of the Pliocene Pontic lake, in the centre of Europe in the Vienna Basin, with those of the Mediterranean coast, as Vienna is situated nearly 1000 miles from the mouth of the Danube. The speaker had shown the close relationship between the terraces



Fig. 2. - Section shewing Gradients of the Lower Avon River-Terraces.





near Vienna, and those of the Danube at the Iron Gates near Orsova (Eastern Carpathians) and in Rumania. From Vienna the Pannonian basin extended as far as Orsova, and was separated by the Carpathians from the Pontic basin that covered the area of the Black Sea. The short valley of the Iron Gates (about 100 miles long) is the connecting-link between the terraces observed on each side of that mountain-range, at the same relative altitudes above the level of the river. So it would appear that the shoreline of the Vienna Basin was only 100 miles distant from the Mediterranean Basin. Consequently, the intermittent relative subsidence of the water-level in the latter had been reproduced near Vienna as the short river cut its valley along a parallel line through the mountain-range. From 600 down to 150 feet, the terraces produced by the lake are recognizable, and later on in the lower stages those produced by the Quaternary fluvial erosion. The meaning of the similar occurrences on the Atlantic coast and in the Mediterranean Basin is not yet fully explained.

Prof. J. E. Mark congratulated the Author on having brought before the Society a paper containing valuable new facts, and such inferences therefrom as appeared to be fully justifiable, without entering into detailed comparisons between the deposits found in

the area dealt with by her and other areas.

Mr. A. S. Kennard said that, with regard to the mollusca, the most important point was the discovery of *Corbicula fluminalis*. In this country it had hitherto only been known from the Thames-Rhine drainage area, but it was now shown to occur in the Severn area. The speaker wished to protest, though not with reference to this paper, against the frequent misuse of the term cold fauna: neither *Elephas primigenius* nor *Rhinoceros antiquitatis* indicated a cold climate, for these species occurred in deposits which were clearly not 'cold', and two species could hardly be termed a fauna.

The President (Dr. J. W. Evans) remarked that it was usual to consider that deposition and erosion operated alternately in the formation of river-terraces; but an experience in Kathiawar had convinced him that this was not necessarily the case. Immediately after heavy rainfall in the Gir Forest, a small stream became so swollen as nearly to fill its valley some 50 feet deep and 300 or 400 feet wide. It flowed with great force in the centre, where violent stationary waves were developed, which must have resulted in powerful erosive action on the river-bed. When, however, the water subsided, a thick deposit of loam-like alluvium was found to have been laid down high up on the valley-slope.

The AUTHOR stated, in reply to Mr. Kennard, that the 'cold' fauna of No. 2 Terrace is not merely represented by abundant remains of *Elephas primigenius* and *Rhinoceros tichorhinus*; but Reindeer is also present, together with a suite of animals of less pronounced northern type, including species of *Bos* and

Cervus.

7. The Silurian Rocks of the Central Part of the Clwy-DIAN RANGE. By Mrs. Ethel Gertrude Woods, Sc.D., F.G.S., and Miss Margaret Chorley Crosfield, F.G.S. (Read May 7th, 1924.)

[PLATE XI-MAP.]

CONTENTS.

		Page
I.	Introduction	170
II.	Definition of the Area	170
III.	Historical Record	171
IV.	Physical Features and General Description	172
V.	Stratigraphy	172
VI.	List of the Chief Graptolite Localities	181
VII.	Palæontological Notes	183
VIII.	Description of the Map (Pl. XI)	184
IX.	Cleavage, and other Rock-Structures directly due to	
	Crushing and Folding	189
X.	Summary	191

I. Introduction.

In 1906 it was suggested to us by Dr. (now Professor) J. E. Marr that we should examine the little-known series of 'Denbighshire Grits and Flags' in the Clwydian mountains, and endeavour to establish the sequence of the beds. Between the years 1906 and 1909, and again in 1911, we paid a series of short visits to the range, working between the New Mold Road on the south and Caerwys on the north, covering an area of 72 square miles.

Various circumstances then prevented the continuance of our field-work until, in 1922, we decided to revisit the district and to put on record the palæontological evidence that we had so far obtained of the age of the beds, in the hope that it might be of service to future workers. Owing, however, to the rarity and very poor condition of the fossils, the map is admittedly incomplete, and

some of the results are tentative.

We desire to thank very cordially Miss G. L. Elles and Dame Ethel Shakespear for kindly determining graptolites from two or three critical localities, and Prof. Marr for encouraging us to persevere. We also feel very grateful to Mr. W. B. R. King, with whom we have discussed some of the problems raised by the mapping, and whose suggestions have been very helpful.

II. DEFINITION OF THE AREA.

The area described in this paper has Moel Fammau for its centre, and includes the range from the north side of Moel Llŷs-y-coed to Gyrn, a distance of about 5 miles in a nearly north and-

south direction. On the west it is sharply defined by the Vale-of-Clwyd Fault, and on the east by the Carboniferous Limestone.

Two visits were also paid to the Bryn-Goleu district, near Nannerch, and the results which we obtained there confirm those obtained in the south.

Our endeavour has been to work out the stratigraphical succession by means of the graptolite fauna, and thus to elucidate the structure of the range.

III. HISTORICAL RECORD.

There have been few workers on the Silurian rocks of this district. The early work of the late Prof. T. McKenny Hughes 1 is useful, as giving a careful lithological description of the beds, although the geological structure is less simple than he describes it. Of the three Survey Memoirs,2 that on the Geology of Flint, Mold, & Ruthin, by Sir Aubrey Strahan, published in 1890, gives an account of the general structure of the whole range, and our work has been based on this. With the aid, however, of the graptolite fauna, we have tried to map the folds more in detail. The beds were referred by the officers of the Survey to the Wenlock Shale, or possibly part of the Ludlow; but the subsequent detailed work of Miss G. L. Elles 3 and Dame Ethel Shakespear 4 on the graptolite zones of the Wenlock and Ludlow Series has shown that Prof. Hughes (who discovered Monograptus colonus in this region as early as 1866) was justified in correlating the beds with the Lower Ludlow.

The only other work on this region is a paper entitled 'The Lower Ludlow Rocks of the Northern Part of the Clwydian Range ' read at Liverpool last year by Mr. F. H. Edmunds.5

Reference may also be made to Mr. Philip Lake's 6 work, describing the sequence of the Denbighshire Series in the Llangollen area. The recent work of Dr. L. J. Wills & Mr. B. Smith 7 in the same area has helped greatly to confirm us in the views that we had formed as to the horizons, the rocks of Lower Ludlow age in the Moel-y-Faen area being apparently similar to those here described.

1 'On the Silurian Rocks of the Valley of the Clwyd' Q. J. G. S. vol. xxxv (1879) pp. 694-98; 'Notes on the Geology of the Vale of Clwyd' Proc. Chester Soc. Nat. Sci. & Lit. No. 3, 1885; and 'Observations on the Silurian Rocks of North Wales ' *ibid*. No. 4, 1894.

2 'The Geology of North Wales' Mem. Geol. Surv. 2nd ed. vol. iii, 1881;

'The Geology of the Coasts adjoining Rhyl, Abergele, & Colwyn 'Mem. Geol. Surv. 1885; and 'The Geology of the Neighbourhoods of Flint, Mold, & Ruthin' ibid. 1890.

3 'The Zonal Classification of the Wenlock Shales of the Welsh Borderland' Q. J. G. S. vol. lvi (1900) pp. 370-413.

'The Lower Ludlow Formation & its Graptolite Fauna' ibid. pp. 415-491.

 Froc. Liverpool Geol. Soc. vol. xiii (1923) p. 335.
 The Denbighshire Series of South Denbighshire' Q. J. G. S. vol. li (1895) pp. 370-413.

7 'The Lower Palæozoic Rocks of the Llangollen District, with Special Reference to the Tectonics' ibid. vol. lxxviii (1922) pp. 176-226.

We find, however, no evidence of deposits of Wenlock age, nor have we identified any beds corresponding with those of Dinas Brân.

IV. PHYSICAL FEATURES AND GENERAL DESCRIPTION.

The Clwydian Range forms a mountain borderland within the eastern boundaries of Wales. It has the form of a gentle arc, and extends in an approximately north-and-south (magnetic) direction from the neighbourhood of Rhyl to that of Llandegla, a distance of over 30 miles. Its breadth is scarcely $3\frac{1}{2}$ miles across the

widest part.

From anywhere on the ridge, the relations of the range to the surrounding country can be quickly made out. On the west, the broad and fertile Vale of Clwyd, far below, stretches away to the sea at Rhyl, and severs the range completely from the high Silurian uplands of Central North Wales, to which it both geographically and geologically belongs. On the eastern side a long ridge of scarped and terraced limestone-heights runs parallel to it, with a narrow strip of coalfield behind them. The range itself is seen to consist of a chain of summits, usually single, and rarely more than double. These are abrupt by nature, but have often been artificially rounded and flattened to form camps. summits are connected by a ridge about 1000 feet high, with glacially-rounded contours and dented at intervals by cols. From this ridge, the ground slopes steeply on the west, and rather more gently on the east. Numerous spurs, short on the west where they have been cut off by the Vale-of-Clwyd Fault and considerably longer on the east, run nearly at right angles to the main direction of the ridge.

The range culminates in Moel Fammau (1820 feet), which is not only the highest point, but also about the centre of the arclike curve of the range, and several of the spurs mentioned above radiate from it. On the eastern side of the range the valleys and gentler slopes are often drift-covered. This fact, added to the wild moorland character of the higher ground, explains the absence of exposures over wide areas; whereas, on the steep slopes and in the valleys of the west, exposures are frequent. The forms of the slopes and the contours of the cwms, especially on the west side and immediately east of the summit of Moel Fammau, are particularly

graceful.

The highest part of the range consists, for the greater part, of the harder rocks, often of the massive sandstones; while the mudstones, flags, and shales, mainly of the lower and higher horizons, appear on the cols and in the valleys.

· V. STRATIGRAPHY.

We have had difficulty in determining the relative ages of the beds, because of a bewildering similarity in the strata, which is due to the repetition of the same lithological characters at various horizons throughout the series. The general sequence is, from uncleaved mudstones with flaggy and gritty beds, and cleaved mudstones with finely laminated silt-bands (the 'Slab Horizon' of Dr. L. J. Wills & Mr. B. Smith) containing the *Monograptus-nilssoni* fauna, to shales or flags interbedded with thin to thick sandstones, and containing the *M.-scanicus* fauna: these are again succeeded by, first, mudstones; then flags containing *M. tumescens*; and these again by finegrained sandy shales yielding *M. leintwardinensis* in occasional narrow bands.

Graptolites, although generally ill-preserved, allow of the immediate recognition of one horizon in the lower beds: that is, the 'Slab Horizon' of the *Monograptus-nilssoni* Zone. Above

this stage graptolites are rarer or absent.

With the change of conditions in the middle (M.-scanicus) beds, the quantity of coarser detrital material increased. At first, thin, and later, massive sandstones were formed, the graptolite fauna giving place to occasional bands crowded with fragments of tiny brachiopods and crinoids. M. scanicus appears very rarely in the sandstones, but is seen rather more often in the shales and flags, both underlying and succeeding these, being then associated with a somewhat richer fauna. The mudstones which intervene between these beds and the flags with Monograptus tumescens contain frequent casts of a limited number of brachiopod species of Ludlow age, with an occasional trilobite.

Detailed Description of the Beds.

The downward succession is as follows:--

Monograptus-leintwardinensis Zone: Bryn-y-saeson Beds; fine sandstones, brightly-weathering banded flags, and sandy shales, with M. leintwardinensis and M. leintwardinensis var. incipiens.

M.-tumescens Zone (2): Cefn-Goleu Beds; pale striped flags, yielding M. tumescens, M. dubius, and M. crinitus.

(1): Eithinen or Brachiopod-Beds, dark, unbanded mudstones, containing Dayia navicula, Camarotechia nucula, Dalmanella elegantula, Cardiola (Slava) interrupta, and Encrinurus sp.

M.-scanicus Zone (2): Plâs-newydd Beds; pale flags and biscuit-like shales, yielding M. scanicus, M. dubius, M. crinitus, M. uncinatus var. micropoma, M. ræmeri, M. bohemicus, crinoids, and

Beyrichia.

 Penmachno Beds; massive sandstones and crushed sandstones and shales, yielding M. scanicus, tiny brachiopods, and crinoids.

Teiran or Passage-Beds: flags, thin sandstones, and crushed shales yielding M. chimæra, M. scanicus, M. nilssoni, and tiny brachiopods.

M.-nilssoni Zone (3): Rhiwisg Beds or Whetstone Horizon; flags like 'whetstones', yielding M. chimæra, M. chimæra var. salweyi, M. varians var. pumilus, and M. dubius.

M.-nilssoni Zone

- (2): Bwlch-pen-Barras Beds, 'Bluestone' or 'Slab Horizon', flags and shales yielding M. colonus, M. colonus var. compactus, M. varians, M. chimæra, M. nilssoni, M. dubius, M. bohemicus, M. uncinatus var. orbatus, Orthoceras sp., and Cardiola (Slava) interrupta.
- (1): Y Fron-werth Beds, sandy flags yielding M. vulgaris, M. nilssoni, and M. varians.

Monograptus-nilssoni Zone.

The lowest series of beds present in the district is well-developed, and of considerable thickness. The apparent thickness is, however, greater than the actual, as the beds are sometimes folded on themselves, and also because the west side of the range is, in several places, a dip-slope.

The zone falls roughly into three divisions (see above), of which the middle (Bwlch-pen-Barras, or 'Slab Horizon') has

proved useful throughout the district as a datum-line.

(1) Y Fron-werth Flags.—These, the lowest beds of the zone, have been seen at Y Fron-werth (20), in Coed Ceunant (48), near the top of Bwlch-pen-Barras (47), and near Pen-y-bryn (15) on the north-west. They consist of very hard banded flags, of uneven width and varying texture. The rock is grey, but weathers to a pale yellowish or reddish brown, with dark-grey beddinglines. It breaks into irregular blocks, and contains few fossils. The graptolites are: *M. vulgaris* Wood, *M. varians* Wood, *M. nilssoni* Barrande, and *M. colonus* var. compactus Wood (only at Pen-y-bryn).

Beds which seem to succeed these, but are still below the 'Slab Horizon' proper, occur also near the top of Bwlch-pen-Barras (41) and on the slopes above Coed Ceunant (46). They are imperfectly bedded, and similar in colour to the rocks of the 'Slab Horizon'; but they are unbanded, and do not contain the characteristic fauna. In these Monograptus uncinatus var. orba-

tus Wood is frequent.

(2) The Bwlch-pen-Barras Beds or 'Bluestone Horizon'.—The beds which form the middle part of the zone are identifiable with the 'Slab Horizon' of the Glyn Dyfrdwy Beds in the Llangollen area. They have here been found to contain about ten species of graptolites, of which Monograptus colonus var. compactus Wood sometimes occurs in masses. The rock, locally called the 'Bluestone', takes on a very different appearance according to the direction of cleavage, which is, in many places, strongly developed. When cleavage and bedding are parallel, or nearly so, and jointing is also present, as in Rhiwlas Old Quarry (62) and in the great quarry south of Moel Eithinen, the rock

¹ The numerals in parentheses refer to the numbers indicated in the list of graptolite localities and in the map (Pl. XI).

breaks into flat blocks, somewhat similar to the slabs of the Llan-

gollen area, only smaller and less perfect.

The best exposures of this horizon are nearly all on the west side of the range, where the beds cover a wide area on a dip-slope. Their position is owing partly to the eastward hade of the Range Fault, which throws them up on the west side. When these beds are also on the upthrow side of the transverse faults, they extend far up the western valleys, notably the deeper ones of Glyn Arthur, Nant-y-Nê, Bwlch-pen-Barras, and Bwlch-uchaf.

The *Monograptus-nilssoni* Beds do, however, also cover a considerable area in the north-eastern corner of the map, and farther north again are found on the east side in the Penbedw region.

A typical exposure of the horizon in Rhiwlas Old Quarry (62) shows the rock to be blue-grey in colour, weathering reddish and yellowish, and characteristically striped. It consists of fine-grained blue mudstone with narrow closely-laminated bands of whitish silty material, in a fairly constant ratio of 3:1 or 5:1 inches, giving a general effect of pale-grey striped bars with blue spaces. This striping and spacing, which suggests a resemblance to music-ruled paper, is a distinguishing mark of the beds, the lines preserving their parallelism widely in a horizontal direction. The rock breaks most easily in the striped layers, and the graptolites have been found there only. Nodules of material similar to the rest of the rock, but much indurated, occur occasionally in the plane of bedding.

In the quarry 400 yards south of Moel y Gaer (37), mentioned by the Geological Survey, and also in a quarry, Old Mold Road (50), a dark red-brown rottenstone, formed apparently from decalcified nodules, yielded masses of badly-preserved graptolites, which, in

the latter case, stood up in high relief.

(3) Rhiwisg Beds (Whetstone Horizon).—Overlying the 'Slab Horizon' proper are beds, still belonging to the M.-nilssoni Zone, but of different lithological character. These beds, which are well developed in Coed Rhiwisg (72), and can be traced thence to Pen-yr-allt (77), at once suggested to our minds the Moughton Whetstones of Austwick, and we have therefore called this the 'Whetstone Horizon'. The flags are much weathered, and are mainly reddish-brown, but their surfaces and joint-faces show decomposition-bands, parallel one to the other, consisting of circles or ovals of various colours, greenish-blue, light and dark brown, to white or pale yellow. These beds are less fossiliferous than the Bwlch-pen-Barras Beds, the most characteristic graptolite being Monograptus chimæra var. salweyi Hopkinson, but M. chimæra Barrande, M. dubius Suess, and M. scanicus Tullberg have also been found. These beds crop out again immediately north of Cilcen (9, 10, 11) on the east side of the ridge, and have been recognized at Tyn-y-pwll and Colomendy in the Bryn-Goleu area, beyond the northern end of the map (Pl. XI).

In the faunal lists which follow (§ VI, pp. 181–82), the outcrop of these beds can be traced by the distribution of M. chimæra Barrande and its variety salweyi Hopkinson, except for the examples of M. chimæra found in and near Plymog (54) which occur at a higher horizon.

The 'whetstone' feature 1 is not entirely confined to this horizon, being seen occasionally in flags belonging to the M.-tumescens

Zone, as on the Penmachno road (13).

Teiran or Passage-Beds.

As seen in the synopsis (p. 173), the upper beds of the M.-nilssoni Zone pass into a series of gritty flags and thin sandstones, containing both M. nilssoni and M. scanicus, also M. colonus Barrande. These beds are best seen on the hill above Teiran farm: so for that reason, and also on account of the mixed fauna and the intermediate lithological character, we have called them the Teiran or Passage-Beds. They consist mainly of grey sandy flags, unevenly bedded, and occasionally containing decompositionbands, similar to those of the 'Whetstones' below. The beddingplanes show as dark- and pale-grey lines, the irregularity of which suggests current-bedding. At certain horizons are more sandy layers, wispy or lenticular in shape, and containing masses of minute broken brachiopods and crinoid-stems, preserved in crumbly ferruginous material. Bands of bluish-grey, rather coarse sand-stone occur towards the top of the series. The bands attain a thickness varying from 9 to 24 inches, and are interbedded with shales, which are often cleaved at a high angle with the beddingplanes. Included in the sandstones are bands of gingerbreadcoloured rottenstone with tiny brachiopods, crinoids, and corals, similar to those in the flags and just as badly preserved.

The position and the extent of the Passage-Beds are difficult to define, because of their similarity to the rocks above and below them, and because of the extreme scarcity of graptolites. They occupy comparatively high ground, and, as well as on Teiran hill, are seen on the southern slopes of Moel Llŷs-y-coed (6), on the north side of Cefn-y-gadfa ridge (17), and on the summits of

Moel-y-Gaer (33) and Y Foel Fenlli (51).

In highly folded and faulted regions, as near the axis of the range, these beds,² in common with any others that consist of thin sandstones and thick shales, have been greatly crushed and contorted. Apart from their position in the sequence, they can hardly (when in this condition) be distinguished from the higher beds which have suffered in like manner. They can, however, be

¹ This feature was described by Hughes as occurring on the west side of the Vale of Clwyd, in beds which (from their position and description) should correspond to some of our *M.-tumescens* Beds; see T. McKenny Hughes, 'On the Silurian Rocks of the Vale of Clwyd' Q. J. G. S. vol. xxxv (1879) p. 596.

² Well seen near the 1000-foot contour-line on Teiran hill.

recognized occasionally by their containing only small mudstonenodules, whereas the higher beds are characterized by containing phacoidal sandstone-blocks varying in length from a few inches to 18 inches.

Monograptus-scanicus Zone.

This consists of two main lithological divisions:-

- (2) The Plås-newydd Beds, a flaggy and shaly facies yielding a characteristic *Monograptus-scanicus* fauna; and
- (1) The Penmachno Beds, consisting of thin to thick sandstones, with intervening shales. These beds are almost devoid of fossils, except for a few flags and shales at the base, which contain the Monograptus-scanicus fauna.
- (1) Penmachno Beds.—The fossiliferous flaggy beds at the base of this series are very light in colour, are banded, and weather mainly reddish. They are seen on Teiran hill by the stream (44) and at Fron Ganol (36), in both of which localities the characteristic graptolite fauna was found, including also, at the base of Teiran hill, a few trilobite-fragments and Beyrichia.

Above these, the lower and thinner sandstones are pale grey, weathering greenish, and sometimes current-bedded towards the base. The bands are separated by partings of finely-laminated sandy shales. The thick sandstones are pale grey, very compact, hard, fine-grained and micaceous. They generally show no signs of lamination; but in the quarry west of Penline some of the layers are laminated, and a little 'gingerbread rock' is also found. The bedding surfaces are often very uneven, their irregularities being filled in by crushed and twisted shales.

It is these sandstones that crop out all along the main ridge as far south as Bwlch-pen-Barras, and give to the range its trend, as also its bold outlines.

The massive quality of the sandstones does not persist, the bands being thinner and more numerous towards the south. They are at their maximum, for this region, in a sandstone quarry on the ridge north-west of Penmachno (3), the thickest bands measuring 8 feet. On Penline ridge, south of the Penline Fault, is an exposure consisting of about 26 feet of alternating sandstones and shales in thirteen bands, the sandstones varying from 1 to 4 feet in thickness. The quarry west of Penline has sandstones of the same thickness, now being worked; and one of the sandstone-bands on Moel Dywyll measures nearly 8 feet. On Moel Fammau itself no sandstones thicker than about 2 feet have been seen.

Isolated fragments of *Monograptus scanicus* have been rarely found in these sandstones, as at localities 3, 4, 5, & 6 on the map (Pl. XI).

Where the sandstone-bands are thin and the shales thick, as is usual towards the top of the series, the beds have proved very Q. J. G. S. No. 322.

susceptible to the action of the compressional forces that have affected the area as a whole. They are, therefore, seldom found in an uncontorted condition, and, having been much indurated by the folding and crushing, they form distinctive topographical features. These are most conspicuous as the high perpendicular

crags of the Moel Eithinen 'Black Rocks'.

The beds are recognizable as containing dislocated portions of the same greenish-grey sandstone as that which characterizes some of the *Monograptus-scanicus* beds, but these exist here only as phacoidal blocks, about 6 to 8 inches thick, and from 12 to 18 inches long, lying in the cleavage-planes. The shales, which are tightly squeezed and twisted round these blocks, show sheared surfaces, and break up into the finest splintery fragments.

As well as at Moel Eithinen crags, good examples of these crushed beds can be seen on the summit of Moel Dywyll, and their junction with the underlying sandstones is exposed a little below Moel Fammau summit, as well as on the col south of Moel

Eithinen.

Owing to the unyielding nature of the massive sandstones, the softer beds both above and below them have, in areas of special folding, been similarly affected, so that, unless the large nodules can be seen, it is difficult to distinguish the *M.-scanicus* beds just described from the Passage-Beds below the sandstones.

(2) Plâs-newydd Beds.—In a few places the upper M.scanicus horizon is seen to be represented by a series of flags and shales containing the true M.-scanicus fauna. The localities are the quarry near Plâs-newydd (8) on the Penmachno road, and on the summit (23) and the south-western slopes of Moel Fammau. In the Plâs-newydd exposure the beds are grey laminated flags, weathering red, brown, and yellow to nearly white. Graptolites were found on buff-coloured faces of fine-grained biscuity fragments. On Moel Fammau the flags were finely banded in pale and dark grey. The graptolites are tabulated in the lists (p. 181); but Plâs-newydd Quarry yielded also minute

encrinite fragments, tiny corals, and Beyrichia.

The fossils in the M.-scanicus Zone are almost entirely confined to the flags and shaly beds underlying and succeeding the massive sandstones, except where the 'gingerbread rock' occurs among the sandstones and in the crushed beds. This contains casts of tiny brachiopods and crinoid-stems in crumbly nodular masses, with large flakes of white and dark mica. The brachiopods have been doubtfully referred to Dayia navicula J. de C. Sowerby and Camarotæchia nucula J. de C. Sowerby. The graptolite localities can be made out from the lists. Five graptolites have been recorded:—Monograptus scanicus Tullberg, M. crinitus Wood, M. ræmeri Barrande, M. dubius Suess, and M. uncinatus var. micropoma Jækel.

Monograptus-tumescens Zone.

In this zone two kinds of rock have been recognized:-

(2) The Cefn Goleu Flags and

(1) The Eithinen Mudstones or 'Brachiopod-Beds'.

Towards the centre of synclinal cores throughout the area, we find evidence of the presence of beds yielding a M.-tumescens fauna. These outcrops have been recognized on the west side of the range only from Moel Arthur to south of Moel Fammau, and on the east only from Moel Fammau to the New Mold Road.

(1) Eithinen Beds.—Of the two distinct facies, the lower, or Eithinen mudstones, consist of a peculiar dark rock, very hard, and devoid of definite bedding-planes, the surfaces being broken up, almost facetted in appearance, and quite irregular. Sometimes the rock appears twisted: it also varies greatly in thickness, and thins out rapidly. The name 'Brachiopod-Bed' has been given to it, because it is full of cavities left by the casts and shells of often distorted brachiopods, with crinoid-fragments, of a much larger size than is seen in the 'gingerbread-rock' below; an occasional trilobite-fragment has also been found. The numerous fossils and cavities render the rock easily recognizable, but the fossils, being usually much weathered, have ferruginous crumbly surfaces, and are very unsatisfactory to determine. In Nant-y-Nê ravine (24) this rock is closely associated with sandy banded flags containing graptolites, so much so that the same block may be, in part, banded and graptolitic, and the rest unbanded, irregular, and crowded with brachiopods. In this exposure the brachiopodbearing rock quickly thins out and disappears, the main portion consisting of flags.

North of this central exposure of the *M.-tumescens* beds, the Eithinen or Brachiopod-Beds are found on Moel Dywyll and at the base of its faulted western slope. They also occur in Coed Cefn Goleu gorge along with the upper flags and, in the south, they crop out in the lane south of Moel Eithinen farm (70). Here an *Encrinurus* tail, *Cardiola (Slava) interrupta* J. de C. Sowerby, *Orthis (Dalmanella) elegantula* Dalman, *Chonetes* sp.,

and one doubtful Monograptus tumescens were found.

(2) Cefn Goleu Beds.—The succeeding (Cefn Goleu) flags with the zone-fossil have been found in an exposure north of Moel Arthur, immediately east of the boundary, on the road between that mountain and Pen-y-cloddiau. The same flags occur on the Penmachno road, a few yards west of the farm (13). Here they are grey, hard, and finely laminated, with alternating layers of more sandy material. As cleavage and bedding coincide, the rock splits fairly easily, revealing surfaces of a light silvery appearance, sometimes covered with speckly fragments. One specimen of Monograptus crinitus Wood was found, with several of M. tumescens Wood.

In the upper part of the deep cleft north-west of Coed Cefn Goleu, and also on the southern slope of Coed Cefn Goleu itself (30 & 31), the higher part of the zone is exposed. The flags are blue-grey, frequently banded with layers of yellowish or greenish material; when more weathered, the alternating bands are chocolate-brown or white. The split surfaces are very pale grey or brownish, speckled with black. The layers are sometimes curved round torpedo- or egg-shaped inclusions of harder material. The fauna in (31) was puzzling, because we found Monograptus tumescens (sparingly) with several specimens of M. leintwardinensis Hopkinson, which has not elsewhere been found with it. We concluded that here was a junction of the two zones, and the fossils may have been collected from different horizons, although from the same exposure.

In Plymog Quarry (54), where the same flags occur, large nodules are seen in the bedding-planes at two levels. They are larger than those of Coed Cefn Goleu, but otherwise similar.

M.-tumescens beds also crop out at intervals along a line drawn from Plymog Quarry to the south-west of Moel Eithinen farm,

and form the hill of Bryn-yr-odin.

The bluff south of Moel Eithinen farm (70) consists of hard pale-grey flags, weathering reddish brown. The flags have sandy layers which appear on the surface as reddish-brown lines, sometimes weathering to rottenstone and, when split, showing pale-grey speckly surfaces. There are markings in the sandy layers similar to those seen in the 'Whetstones'. Some nodules occur in the bedding-planes. Two specimens of Monograptus tumescens were found.

Monograptus-leintwardinensis Zone.

This zone has been recognized in two localities, one of which, that of Coed Cefn Goleu (30), has been already described.

Bryn-y-saeson Beds.—At Bryn-y-saeson, on the Old Mold Road, the most typical exposure occurs, and we have therefore

given this name to the beds.

They consist of alternating layers of sandstones, grey flags, and more markedly sandy flags and shales, the more sandy shales being towards the top of the quarry. The rock has generally a striped appearance, and as the surface weathers in different shades of rich brown and golden yellow, the effect is striking, far different from that of any other exposure in the area. The flags are hard and silvery-grey, highly micaceous, and show frequent white markings. On the east side of the quarry, about half-way up, graptolites were found in a thin layer of pale-grey sandy rock, sometimes three or four on a slab. These, kindly identified by Mrs. (now Dame Ethel) Shakespear, were Monograptus leintwardinensis Hopkinson and M. leintwardinensis var. incipiens Wood.



VI. LIST OF THE CHIEF GRAPTOLITE LOCALITIES.

								. 1						_			_	1
	M. vulgaris.	M. colonus.	M. colonus var. compactus.	M. nilssoni.	M. uncinatus var. orbatus.	M. varians.	M. varians var. pumilus.	M. bohemicus.	M. chimæra.	M. chimæra var. salweyi.	M. crinitus.	M. dubius.	M. ræmeri.	M. scanicus.	M. uncinatus	M. tumescens.	M. leintwardinensis.	M. leintwardinensis var. incipiens.
1. Lodge Wood, Glyn Arthur												+						
2. Siglen-isaf		+										+				1		
3. Penmachno Lake Quarry 4. ,, anticline (W.)												+	• • •	++				
4. ,, anticline (W.) 5. ,, (E.).											,			5				
6. ,, (within)								+						?				
7. Plas-newydd, old quarry												+	+	+		1		
west of. 8. Plâs-newydd Quarry 9. Pedair-groesffordd			r			2			+		с	+	+	С	+			
10. Pistyll farm			r			+												
12. Garth stream				5	5											1		
13. Penmachno Road Quarry									+		+				•••	C		
14. ,, levels (N.) 15. Pen-y-bryn and Tyn-y-	+							+	-			+				1		
pistyll.	ľ				}													
16. Penmachno levels (S.) 17. Garth Quarry	ļ			5					١.									
				1		+			+									
18. Nant-y-gain (above the reservoir).		+		1		T												
19. Cefn-y-gadfa ridge												+						
20. Y Fron-werth	+			+		+						+						
21. Brithdir-mawr			•••									т.		+				
21 a. Pant Iago												l		+				
23. Moel Fammau summit (N. & S.).											+	+	+	+		c		
24. Nant-y-Nê source												+	(
26. Nant-y-Nê (lower stream					С	,,,		5				+						
by boulder). 27. Nant-y-Nê tributary (S.).		+			c				+	с			+					
two localities. 28. Nant-y-Nê, 2nd tributary														+				
by spring. 29. Coed Cefn Goleu (gorge and																c		
hole above stream).																+	c	+
30. Coed Cefn Goleu, localities		•••						•••			1							
31. ,, ,, locality 3																+	+	
32. Moel y Gaer, col and quarry			+		+	+		+				С						
33. " " camp			3	+		+	+		+					c				
34. Fron-gôch 35. Moel y Gaer (above stream		+	с	+				+										
E. of).																94		
36. Fron-ganol								++	+					+	•••	r		
37. Moel y Gaer (quarry			С	r				7										
38. ", " old quarry opposite.										c								+
39. Bryn-y-saeson													,		•••		C	+
40. Fron-hên farm				T.	c		1				***			1				
41. Bwlch-pen-Barras (Llan- ferres side).				r									1					
	_																	

	M. vulgaris.	M. colonus.	M. colonus	M. nilssoni.	M. uncinatus var. orbatus.	M. varians.	M. varians var. pumilus.	M. bohemicus.	M. chimera.	M. chimera	M. crinitus.	M. dubius.	M. ræmeri.	M. scanicus.	M. uncinatus	M. tumescens.	M. leintwardinensis.	M. leintwardinensis var. incipiens.
42. Moel Fammau, footpa	ath	+	С								2	+						
43. Moel Fammau, lower fo path, exposure near.	ot-									***					P			
44. Teiran stream quarry							***				+	+		c				
45. Teiran hill and old quar 46. Coed Ceunant, quarry			+	+	С.		***			***	+	4 10 1		+				
900-foot contour-line. 47. Bwlch-pen-Barras, top a	nd +	+		+	+					***		+						
near the top. 48. Coed Ceunant			P	С	+	c												
49. " old quarry 50. Old Mold Road Quarry		+	с	+		+					1-0.1	+						
51. Y Foel Fenlli (summit) 52. Llanferres Rectory (near					+	***	***		117	***	141							
53. Llwyn Moelyn							1994	5		***					+			
54. Plymog Quarry 55. , bluff above							***		+	144	•••		5	+		+		
56. " stream 57. Fron-heulog		•••				+	***	+	+	+		6+			***	+		
58. Y Foel Fenlli (S.E. slope 59. Bwlch-crûg-glâs (N. 1	e).											***		5				
lock).									***	***				1				
60. Blaen-y-nant		'	С			+						++						
62. Rhiwlas farm and quarry.	old		c	+	***			• • •				+	ì					
63. Sawmill cottage			c +	+		+									1			
65. Moel Eithinen, spur west	of	+		+	+	e												
67. Bryn-yr-odin						+			+	+				5	+	+		
68. Ty-isaf		+		+			+				+							
70. Moel Eithinen farm, resouth of, and bluff.	oad															+		
71. Rhiwisg stream above ro	oad					+	***			+								
73. Wernog quarry		1	c	++	++	t	***			+								
74. New Mold Road, B.M. 8 75. Gyrn		C	.с						e			+						
76. Bwlch uchaf	ties		+	+		С		+	+			c		+				
(outside map, south of 7	73).			}					1						1	}]	1
Localities found i	n the	e E	Bryn	G	oleu	. a:	rea,	no	rt	h of	tl	ı e	ma	ар	(PI.	X	I).	
Tyn-y-pwll Quarry above Tyn-y-pwl Lodge, Caerwys Maes-yr-esgob Colomendy Barn Pen-isa'-r-cwm		+ c+	***		***	c	0.00		+	***				+2.	+	+		
Tan-yr-allt Penbedw-uchaf Near A in Range (on t 6-inch Ordnance Surv map).	he	1+	***	2			•••			***		+	- 4 4			+		

VII. PALÆONTOLOGICAL NOTES.

Regarded from the palæontological point of view, this district is almost devoid of interest: no new species have been found, and no really good specimens of already-known species. Certain features are, however, noticeable in the distribution of the species, which might prove of importance if found repeated in other areas.

The points that we have noted are:

(1) Monograptus uncinatus var. orbatus Wood is found alone in an unbanded mudstone below the more fossiliferous beds of the 'Slab Horizon': it may, therefore, be possible to use this species, when it occurs thus, as indicative of a low horizon in the M.-nilssoni Zone, higher, however, than the Y Fron-werth Beds.

(2) Monograptus nilssoni Barrande itself is comparatively uncommon; it has been found more often in the upper part of its

zone, but even then less frequently than other forms.

(3) Monograptus colonus var. compactus Wood seems to be the commonest variety of the colonus type. Even if we make due allowance for the distortion caused by crushing, the thecæ are too close together for M. colonus proper. The species has been found very commonly in balls of rottenstone (probably decalcified concretions), and is then sometimes only recognizable by its form and colonial habit. It is found throughout the M.-nilssoni Zone in this area, but seems to mark a definite horizon where it occurs in masses. This horizon corresponds to part of the 'Slab Horizon' of Dr. L. J. Wills & Mr. B. Smith, and is rather near the top of the Monograptus-nilssoni Zone.

(4) Monograptus crinitus Wood was recorded by Dame Ethel Shakespear as a new species from Lower Winnington, and there occurred in the M.-nilssoni beds only. We have found it, however, several times with M. scanicus, in localities where no other graptolites were seen, and once with Monograptus tumescens. We, therefore, believe that here it passes upwards, at least into the M.-scanicus Zone. We have found it, but more rarely, in the

Monograptus-nilssoni Zone also.

(5) Monograptus chimæra Barrande and M. chimæra var. salweyi Hopkinson have been found here, either alone, or with Monograptus dubius Suess. Because the beds in which they occur differ also in lithological character from those of the 'Slab Horizon' and dip over them, we have tried by means of these fossils to distinguish a higher horizon, forming the top of the Monograptusnilssoni Zone.

(6) The specimens identified as Monograptus leintwardinensis Hopkinson and M. leintwardinensis var. incipiens Wood were found together, as was recorded by Miss G. R. Watney & Miss E. G. Welch 1 in the Cautley and Ravenstonedale district. Dame Ethel Shakespear's view, that the incipiens variety probably characterizes a slightly lower horizon than M. leintwardinensis proper,

^{&#}x27; 'The Salopian Rocks of Cautley & Ravenstonedale' Q. J. G. S. vol. lxvii (1911) pp. 215-37.

seems borne out by the fact that the variety here occurs in close proximity to Monograptus tumescens Wood, and strengthens the supposition that only the lower beds of this zone occur in the district.

(7) A few common species of brachiopods of the ordinary Ludlow types have been found in several localities, in beds overlying those which contain *Monograptus scanicus*. The most frequent forms, often much distorted, are *Dayia navicula J. de C.* Sowerby, *Dalmanella nucula J. de C.* Sowerby, and *Atrypa* sp. The 'tiny brachiopods' so often recorded from the more gritty flags seem to recur wherever the facies is suitable for them. They begin in the Passage-Beds, just above the *M.-nilssoni Zone*, and continue into the zone of *M. scanicus*; they have not been found in the *M.-tumescens Zone*. Cardiola interrupta J. de C. Sowerby, which occurs commonly with the brachiopods, is found also in other beds, especially in the *M.-nilssoni Zone*.

VIII. DESCRIPTION OF THE MAP (Pl. XI).

The map shows that, generally speaking, the western slopes are covered by the lowest beds occurring in the area, those namely of the M.-nilssoni Zone. Harder and more massive beds occupy the central part of the mountain-mass east of these, and are generally referable to the M.-scanicus Zone. Continuing eastward, but only in the southern part of the map, where the sequence seems less interrupted, we see the higher beds of the Ludlow Series, the Monograptus-tumescens and M.-leintwardinensis Zones, forming synclinal cores.

More detailed examination reveals that, lower down the western slopes in the northern part of the map, wherever the harder beds are not immediately cut off by the fault mentioned below, exposures of flags with the *M.-tumescens* fauna occur, and probably these beds cover a wider area than we have shown on the map, as we have not ventured to separate them from the *Monograptus*-

scanicus beds on lithological evidence only.

The explanation of the extensive exposure of *M.-nilssoni* beds on the west, apparently dipping over the newer beds, is that, immediately west of the mountain-ridge, in the area here described, the beds of the *M.-scanicus* and *M.-tumescens* Zones are everywhere faulted against those beds. The fault (marked on the map as Range Fault (west)) is north-westerly to north-north-westerly in general direction: that is, parallel to the trend of the range as a whole. Its downthrow is north-easterly and north-north-easterly, and partly owing to its easterly hade, but also owing to the throw of the transverse faults, the *M.-nilssoni* beds are carried far up the deeper valleys eastwards, sometimes over the cols.

This very important fault, although frequently broken by the later faults, extends the whole length of the area mapped, and has influenced, if not altogether determined, the direction of the range. The dip of the beds on the western slope is persistently westward

to south-westward, except in localities where it is complicated by the minor folds. The amount of dip is very variable; it is generally steeper than the slope of the ground, but occasionally

coincides with it so that a dip-slope is formed.

On the gentler eastern slope the relations and distribution of the beds are less clear, as there is more cultivation, and wide areas are devoid of exposures. We are, therefore, very diffident as to the correctness of our map in this part. In the northern part the *M.-nilssoni* and Passage or Teiran Beds are almost confined to the Nant y Gain valley, which leads down to Cilcain; while the stream that descends past Y Fron-werth, although rising in *M.-nilssoni* beds, traverses mainly *M.-scanicus* beds. From Moel Fammau southwards only beds of the three higher zones crop out in the eastern valleys and on the spurs, except in the extreme south.

North of the Y Fron-werth Fault a south-westerly dip predominates even on the east side of the range, except in certain anticlinal and synclinal folds, such as those of Plâs-newydd and Penmachno, where the beds have been able to withstand the effects of pressure and packing. South, however, of this fault, which may be considered a master-fault of the district, the folding is more nearly east and west, and there is, very frequently, an easterly

component in the dip, which is lower.

Corresponding to, and nearly parallel with, the Range Fault west, there seems to be on the east side a fault, or series of faults, not easily traceable in these unfossiliferous beds. This fault, where it occurs north of the Y Fron-werth Fault, throws down to the west. South of this, like the main Range Fault, it has a downthrow to the east, and drops higher beds on the east of the range,

against those that dip under the central mass.

Another series of important faults runs transversely to the direction of the range (that is, north-north-west and south-southeast in the north of the map, east and west in the centre, and south-east and north-west farther south) and cuts the Range Faults at a high angle. These faults are subsequent to the Range Faults, which are consequently shifted by them. The downthrow of these faults is generally on their north side, like most of those in the Carboniferous rocks; but the Moel Fammau Faults throw down southward, as does the Cefn-y-gadfa Fault, thus resembling the Pant-y-mwyn Fault east of it. The effect of these transverse, or rather, radial faults, on the general structure is seen in the shifting and overlapping of the main folds, with the result that the whole area has been cut up by block-faulting into wedges, most of which have apparently, from south to north of the map, been shifted en échelon in a westerly direction.

Owing to the presence of the radial faults, the map falls naturally into segments of a wide circle, which can be described separately.

Segment I: Moel Arthur to Penline Fault.

In this segment the faulting causes the M.-nilssoni beds to run up Glyn Arthur eastwards to the 1000-foot contour-line, a little above

Lodge Wood. They also extend up the valley to the north. The *M.-scanicus* beds, which are faulted against them, are folded along anticlinal and synclinal axes running nearly east and west, or slightly north of east and south of west. Moel Arthur is near the axis of an anticline, and Moel Llŷs-y-coed summit lies in the axis of a syncline. The Moel Llŷs-y-coed Fault, which separates this segment into two parts, has shifted the northern part of the segment to the east, and the *Monograptus-nilssoni* beds in Glyn Arthur have probably been shifted eastwards again by a transverse fault that we have not traced.

In the southern part of this segment, between the Moel Llŷs-y-coed and Penline Faults, the downthrow of the latter has brought the closed-in end (6, 7) of the big Garth-Penmachno anticline against its broader part (12) on the upthrow side of the fault. The western limb of this closed-in end has been broken by the Range Fault (east) and, by means of a parallel fault hading eastwards, has been let down against the M.-nilssoni beds, which form the outer part of the limb continuing the first Moel Dywyll syncline. The Penline Fault has also shifted the main Range Fault (west) considerably to the west, so that it runs not far from the Vale of Clwyd Fault. In the eastern limb of this anticline, near Plâsnewydd (8), is one of the best exposures of graptolitic Monograptus-scanicus beds. Throughout this segment the beds pitch westwards or slightly north-westwards.

Segment II: Penline Fault to Y Fron-werth Fault.

In this segment, owing to the northward downthrow of the Penline Fault, the Range Fault (east) is west of its former position; while the main Range Fault (west) is seen slightly east of its position in Segment I. Between the Range Faults, the massive sandstones and crumpled shales of Moel Llŷs-y-coed and Penmachno are continued as the long high ridge of Penline, and outline a syncline, a broken anticline, and a second synclinal fold southwards, all three of which together make up the mass of Moel Dywyll. Probably part of the deep valley south of Penline contains *M.-tumescens* flags, resting upon the fossiliferous *M.-scanicus* beds of the upper slopes; but we have not been able to identify them.

East of the summit of Moel Dywyll, which is within the second synclinal axis, steplike platforms are seen alternating with escarpments of crushed and twisted rock (of which the actual summit is formed), the nearly level surfaces representing, probably, the dipslopes of the sandstones, partly filled in with heather-covered débris. The steplike platforms of grit with intervening contorted shales are a striking feature wherever the higher beds of the *M.-scanicus* Zone are found. They are well seen on the southern flanks of Moel Llŷs-y-coed, and form the 'collar' of Moel Fammau. Down the western slope of Moel Dywyll they are repeated several times by small step-faults, which give to the slope its curious jumpy outline. These are cut off on the north by a transverse

fault, which seems to continue across the range eastward separating the low *Monograptus-nilssoni* horizon of Y Fron-werth from *M.-scanicus* beds on the north.

East of the central mountain-block, which is bounded by the Range Faults, the broad double-topped Garth-Peumachno anticline, with its centre near the lower reservoir, exposes the higher *M.-nilssoni* beds west of Cilcain. These are separated from the *M.-scanicus* beds of the Cefn-y-gadfa ridge by another transverse fault.

In this segment the anticlines and synclines still pitch west-wards.

Segment III: Y Fron-werth Fault to Moel Fammau Fault.

The faulted block between these transverse faults consists of a broad synclinal fold, in the axis of which appears the summit of Moel Fammau. The syncline has no pitch, and, wherever the dip coincides with the slope, as it does west and south of Pwll-vrhôs, the sandstones cover a wide surface of the hill-slope. The M.-scanicus beds of Moel Fammau summit are succeeded by the lower (Brachiopod) beds of the M.-tumescens Zone (24), which are exposed in the centre of the syncline; but the gorge of the Nant-y-Nê being steeper than the dip of the beds, these last quickly disappear, and the valley-sides are formed by beds of the M.-scanicus Zone. The sandstones and contorted bands seen near Moel Fammau summit are similar to those on Moel Dywyll, and the edges of the grit platforms can, from the Cilcain side, be observed clearly outlined against the sky. The Moel Fammau Fault can be traced crossing the bed of the Nant-y-Nê's southern tributary, where it separates the M.-nilssoni beds from those of the M.-scanicus Zone. East of Moel-y-gaer col it truncates the grit-bands and bands of contorted rock of the M.-scanicus Zone south of it. On the north side of Moel-y-gaer, the Moel Fammau Fault, together with another on the north side of Nant-y-Nê and parallel to it, brings a block of M.-nilssoni beds high up that valley, with Passage-Beds north and south of it in the lower part. On the south and east sides of Moel Fammau summit, the main gritbands of the col are cut off by the Moel Fammau Fault. farther eastward course we do not know, but there seems to be a fault from it which, following a north-easterly direction, has brought the Monograptus-scanicus beds of Ffrith Mountain against the Teiran Beds of Moel Fammau's eastern slope. Exposures of the Ffrith Mountain beds are seen at 21, 21 a, and in Eilum stream (22).

Segment IV: Moel Fammau Fault to Bwlch-pen-Barras Fault.

It was noticed that in the Moel Fammau segment the beds were without pitch; from about this region southwards, on the other hand, the pitch is uniformly towards the south-east: that is, the opposite way to its direction in the north of the map.

The position of the main Range Fault is marked by the abrupt termination of the sandstone-bands encircling Pen Barras and the steep drop on the west side of the high north-and-south ridge of sandstones and crushed beds, which abuts on the Moel Fammau Fault.

West of the Range Fault the *M.-nilssoni* beds are succeeded by Passage-Beds which, on the north side of Teiran hill, exhibit fine examples of crushing. Good fossiliferous exposures of *M.-scanicus* beds succeed towards the foot of the hill (44).

We have not been able to trace with certainty the Range Fault (east) in this segment; but it may cut out part of the beds marked as belonging to the *Monograptus-tumescens* Zone west and south-

west of Eilum stream.

The whole of this segment, east of the Range Fault, forms part of a big broken syncline, with its axis running north-west and south-east, as contrasted with the Moel Fammau syncline, which runs west and east. In the centre of this syncline in Coed Cefn Goleu (30), the Monograptus-leintwardinensis beds are exposed.

Segment V: Bwlch-pen-Barras Fault to Plymog Fault.

The combined effects of faulting and denudation south of the Bwlch-pen-Barras Fault have caused the *M.-nilssoni* beds to extend not only to the top of the col, but also some distance east of it (41). Very few exposures are seen on Fron-hên, and these consist of sandstones and crushed beds (40, 52, 55) succeeded eastwards by beds containing the *Monograptus-tumescens* fauna (54).

A branch fault repeats the M.-leintwardinensis beds at Bryn-y-

saeson (39), and carries them farther west.

South of Bwlch-pen-Barras, the dip-faults, which cross the range transversely, no longer run north of east to south of west, but south of east to north of west. This change of direction does not take place suddenly, as is indicated by the forking, seen in the Carboniferous Limestone, of the Pant-y-mwyn and Pant-y-buarth Faults, which form the eastward continuation of the Y Fron-werth Fault.

Segment VI: Plymog Fault to New Mold Road.

This segment is traversed by two dip-faults, both running nearly parallel to the eastern part of the Plymog Fault, the westward continuation of which seems to curve round and continue down Coed Ceunant, where, low down, the lower *Monograptus-nilssoni* beds are found.

The main Range Fault is here almost central on the map, and is actually east of the mountain-ridge, which culminates in Y Foel Fenlli, so that the *Monograptus-nilssoni* beds extend as far eastwards as Fron-heulog (57), and on to the eastern slopes of Moel Eithinen (66).

East of the Range Fault, the sandy beds of the M.-scanicus

Zone appear, succeeded again eastwards by the *Monograptus-tumescens* beds in Plymog stream (56) and near Bryn-yr-odin (67).

Thus, in this part of the range, the sandstones no longer occupy the ridge, which is continued by faulted fragments of the tough sandy Passage-Beds, and also by the crushed beds, which elsewhere succeed the massive sandstones. The summit of Y Foel Fenlli consists of the harder beds of the M.-nilssoni Zone on the east side: but a few Passage-Beds seem to be faulted in on the west side. Two similar north-and-south faults, on the south side of the Bryn-vr-odin Fault, let down the crushed M.-scanicus beds west of Moel Eithinen. These beds form the Moel Eithinen 'Black Rocks', also the ridge and hillocks (59) of Bwlch-crûg-glâs. They appear again on the eastern slopes of Gyrn, being shifted by the Ffynnon-y-berth Fault. The north-and-south fault, which separates these from the M.-nilssoni beds on the west, may be the Range Fault, but can only be identified with certainty by examining the beds south and east of the New Mold Road. South of the Bryn-yr-odin Fault the M.-nilssoni beds crop out on both sides of the New Mold Road, and must, therefore, be faulted against the *M.-tumescens* beds west of them.

Our map does not show the details of the smaller anticlines and synclines, nor the minor faults and disturbances inherent in a district of so complex a nature.

IX. CLEAVAGE, AND OTHER ROCK-STRUCTURES DIRECTLY DUE TO CRUSHING AND FOLDING.

All the rocks in this area that are capable of cleavage develop this structure more or less, according to their nature and position in the folds. The strike of the cleavage persists in one main direction throughout the range, and is roughly a little north of west and south of east, varying between west 10°-30° north and east 10°-30° south as outside limits. The cleavage-dip is usually southward at a fairly steep angle. Where, in a few places, it is northward, the change is due either to local faulting, or possibly

to regional torsion.

In addition to the cleavage, conditions of strain and stress are very noticeable, especially towards the axis of the range. Each kind of rock behaves under these conditions in an individual manner; but, owing to the lithological similarity of many of the rocks, it is often extremely difficult to recognize in its final compressed condition a rock familiar in its original uncrushed state. The rocks least affected are those of the 'Slab Horizon' in the M.-nilssoni Zone. These are characterized by fairly good cleavage, but otherwise compression has produced little beyond jointing. If cleavage and bedding are at a slight angle one to the other, the joints allow these rocks to split into large slabs with the bedding-planes crossing them like bars of music, as seen in the big quarry on the New Mold Road. If cleavage and bedding are at a

wider angle one to the other, the beds resemble, from a distance, bundles of faggots, and split into narrow lath-like fragments sometimes 2 or 3 feet long. The bedding-face may be curved, and then one piece can be pulled out from another like a sword from its sheath. These features are well seen in the quarry 400 yards south of Moel-y-gaer, visited by the officers of the Geological Survey.

Special effects of jointing are seen also in the thick beds of flags which succeed the 'Slab Horizon'. In Pedairgroesfford (four cross-roads) Quarry, innumerable joints break up the flags into short lengths, forming little blocks from the size of a matchbox upwards. The concentric decomposition-lines of various colours, which characterize the higher beds of the M.-nilssoni Zone, always

show on the joint-faces as well as on the bedding-faces.

More remarkable are the pressure-effects observable in the Passage-Beds and *M.-scanicus* beds respectively, which correspond in age with the 'internally crumpled' beds of Dr. L. J. Wills & Mr. B. Smith. Occurring as they do near the axis of the range, and in or near the cores of the chief folds, sometimes indicating the collapse of the central part of a fold, these appearances afford some measure of the enormous amount of compression to which the Silurian rocks have been subjected, and also illustrate the varying effects of such pressure when acting on different types of competent and incompetent rocks which are interstratified.

Taking the kinds of rock thus affected, in the order in which

they occur, we find:

(1) Thick shaly deposits, sometimes without visibly-accompanying sandstone-layers, although the structure is due to the presence of the sandstones. The appearance produced varies according to the surface exposed. If this is parallel to the bedding, and at right angles to the direction of pressure, the shales shatter into tiny shelly flakes, and the surface of the rock presents an appearance of wavy lines enclosing ovoid spaces, forming a regular pattern. Good examples of this phacoidal structure occur on Moel-y-gaer and near the 1000-foot contour-line on Teiran hill, both of which belong to Passage-Beds. Elsewhere ovoid hollows or ridges are observable on the under surfaces of some of the sandstone-layers, as on Penline ridge and in the quarry west of Penline, which are in the *Monograptus-scanicus* beds.

When the surface exposed is at right angles to the beddingplane, the appearance is that of irregular splinters squeezed together, and breaking up into match-like fragments, as at Bwlchcrûg-glâs. Some of these beds on Moel Dywyll's western slope, much weathered, look black and almost cindery. Such beds are usually crumpled and weathered to an extent that nearly or quite obliterates their stratification. They may occur wherever the necessary conditions prevail, but generally belong to the upper M.-scanicus beds above the massive sandstones, or may in some

^{1 &#}x27;Geology of Flint, Mold, & Ruthin' Mem. Geol. Surv. 1890, p. 6.

cases represent them. A doubtful specimen of *Monograptus scanicus* was obtained at Bwlch-crûg-glâs.

More flaggy beds of this type are seen on the col between Gyrn and Moel Eithinen, also on Moel Fammau, north-east of the summit, where sheared and contorted flags rest upon a massive

sandstone-band, the surface of which is strongly rippled.

(2) Thin bands of shales or flags, interbedded with massive sandstones, show the effects of crushing mainly in the softer rocks. The shales, for instance, are then often cleaved at a very steep angle to the bedding, presenting the appearance of Roman tilework. More often they are twisted up and squeezed into the irregularities in the sandstones, so as to adhere tightly to them. Examples can be seen on the Penline ridge and above Penmachno.

(3) Deposits which consisted originally of thick shales or flags interbedded with sandstone-bands present the most striking features of crumpling in the area. Beds of such material precede, but more conspicuously follow, the massive sandstone series. Here, wherever great compressional force has been applied, the flags are thrown into strong folds; the sandstones, being more rigid, have been dislocated into blocks, and their edges worn away by crushing and shearing, so that they now remain as nodular or phacoidal masses. The direction of the folding is indicated by these blocks, as they have been dragged with their long axes parallel to it; while the interbedded shales and flags are twisted in and out of the sandstone fragments.

These beds are at once recognizable in the field, where they form outstanding and often elevated features. The elbow of contorted rock west of Moel Eithinen summit, and locally known as the 'Black Rocks', is one of these. The knolls on the ridge of Moel Llŷs-y-coed and the summit of Moel Dywyll consist of the same intensely hard rocks, which are almost of the nature of crush-

conglomerates.

It seems impossible to find, much less to identify, fossils in these rocks, and their aspect being so changed from that of their normal uncrushed condition, their correlation is a matter of inference, drawn from a great many localities, unless they are found in normal juxtaposition with rocks of known age, a circumstance which rarely occurs.

X. SUMMARY.

The Lower Ludlow rocks, which form this part of the Clwydian Range, have, in common with other parts of the Pre-Carboniferous floor of North Wales, been subjected to great compressional and torsional forces which, in this case, have thrown the beds into a succession of anticlines and synclines, crossing the present range in directions varying from north-north-west and south-south-east to east and west. Subsequently, the range was elevated in a gentle anticlinal arch running in a general (magnetic) north-and-south direction, and separated by faulting from similar formations on the west, permitting the rocks to move with some individual freedom.

The amount of force exercised has been so great that every magnitude of folding is observable, from the puckering seen in a hand-specimen to alternating synclines and anticlines of mountain size.

The influence of the forces is traceable also in the cleavage, crushing, shearing, and faulting of the beds and in the block-like

fracturing of the range.

The individual note is struck in the contrasting pitch of the beds north and south of Moel Fammau, and in the radial character of the transverse faults, which diverge along lines suggested by the forking of the Y Fron-werth Fault where it is continued into the limestone, and thus 'vertebrate' the range into wedge-shaped blocks.

These peculiarities we ascribe to the influence of the Harlech Anticline, the axis of which, if continued, would appear to emerge in the neighbourhood of Moel Fammau.

EXPLANATION OF PLATE XI.

Geological sketch-map of the central part of the Clwydian Range, on the scale of 3 inches to the mile, or 1: 21,120.

DISCUSSION.

Mr. C. B. Wedd congratulated the Authors on the completion of a decidedly arduous undertaking, and on the interesting results Having long been engaged (in conjunction with Mr. Bernard Smith) in a study of the tectonics of a wider region, which included the Clwydian Range, he had felt the want of a detailed knowledge of the range and its manner of folding, for the greater part of that tract had not been mapped during the recent re-survey of the North Wales Coalfields. He was glad to find that the Authors had demonstrated by mapping a structural arrangement similar to that which his colleague and he had formulated as a general inference without knowledge of detail, for Mr. Smith had carried his own mapping northwards into the southern part of the Clwydian Range, but had had no opportunity for an adequate examination of the whole. Still, they had themselves inferred a radial disposition of folds in the Lower Palæozoic rocks (with differential movement along radial fault-lines) as initiated before the transverse arching of the whole range into a crescentic anticline, during the progress of a much wider torsional movement in which the Clwydian anticline was dragged bodily round by east to south along a 'clockwise' curve.

On one point the speaker had perhaps not rightly understood the Authors' meaning: for he was unable to follow their seeming conception of a 'counter-clockwise' combined with a 'clockwise' direction of movement, in the two parts of a structure with similar axial curve throughout. But their recognition of an increase of axial bending in the southern part of the range, from a pivotal position in the middle of it, was interesting, and harmonized

with the spiral tendency of the whole movement.





The main tectonic processes as affecting the Flintshire Coalfield with the greater part of the Clwydian Range (so far as the speaker and his colleague understood those processes) had been sketched in a new Geological Survey Memoir already due for publication; but the tectonic principles of that district could not be interpreted apart from the larger whole affected by those principles.

The speaker concluded by suggesting the connexion between the

Clwydian folds and other structures in the neighbourhood.

The Secretary read the following contribution to the Discussion, received from Mr. Bernard Smith:—

'The work done by the Authors is of extreme interest, and proves that the occurrences of Wenlock rocks in this district are confined to the area south of the east-and-west Llanelidan Fault. This fault cuts off the Carboniferous Limestone at the southern end of the Vale of Clwyd, and throws it against the

highest Ordovician rocks, which are exposed near Moel Cricor.

During the recent re-survey of the Liangollen Sheet and its margins, Ludlow rocks were found by the writer to extend as far north as the latitude of Gyrn or Ruthin, on the west side of the Vale. They occurred in east-and-west folds with little or no pitch, and comprised the Monograptus-scanicus, M.-tumescens, and M.-leintwardinensis Zones. Upon the east side of the Vale the beds are rolling also, but not so regularly as on the west side. The strike of the folds is nearly due east and west, but the pitch is eastward. The zones represented were those of M. nilssoni, M. scanicus, M. tumescens, and possibly M. leintwardinensis, although the characteristic fossil of the last-named zone was not found. Generally speaking, the higher beds occur upon the eastern flanks of the range, in accordance with the pitch of the folds. Thus the results of the re-survey agree in many particulars with those of the Authors, and the two areas are closely linked up.

'With regard to the torsional movements described, these must be considered part of a much greater system that comprises a large portion of North Wales. The torsion, for example, has resulted in a great movement

eastward of all the rocks occurring south of the Llanelidan Fault.

'As a point of minor criticism, the term Lletty Beds' may be misleading, as there are three farms of that name, two on the west and one on the east of Penmachno.'

Prof. P. G. H. Boswell thought that the Authors were to be complimented on the thorough and successful manner in which they had elucidated the succession and described the graptolitic faunas of the Lower Ludlow rocks of the area. The difficulty of the investigation was not lessened by the monotony of the lithology of the deposits, by the presence of cleavage, by the frequently poor state of preservation of the fossils, and by the grass-covering of much of the country. It was doubtless due to the unpromising nature of the beds that little work had been done on the Silurian rocks of the Clwydian Range since the early accounts of the Geological Survey.

As a point of minor importance, the speaker hoped that the Authors would not persist in their use of local Welsh names (so great a burden on the memory) for the various divisions, which could be satisfactorily defined by combined lithological and stratigraphical terms, as, for example, the 'leintwardinensis flags'. It was noteworthy that Mrs. Woods, in her admirable account of

¹ [This term has since been discarded by the Authors in revising the paper previous to publication, and the term Plas-newydd Beds substituted therefor.]

the succession that evening, had not found it necessary to use the local names introduced into the abstract.

He would also offer the suggestion that cessation and quickening of current-action, combined with changing direction of drift, might well explain the limited lithological variations in the deposits, without recourse to the hypothesis of advancing or retreating shore-

lines and the passage of earth-movements.

In connexion with the tectonics, he desired to ask in what sense the term 'Caledonian' was used. The faults so described appeared to vary in trend from the accepted direction almost to north-west and south-east. The evidence on which the movement along certain faults was adduced as being largely horizontal seemed to call for further exposition. The conception also of torsional movements, clockwise and anticlockwise, and of a block which formed a 'pivotal line' was difficult to comprehend. The warping of pre-existing structures in the Ludlow rocks by post-Carboniferous movements would appear to be sufficient to explain some of the apparent tectonic anomalies.

Mr. W. B. R. King congratulated the Authors on behalf of Prof. Marr and himself on the completion of this work. He considered that an accurate record of the numerous fossil localities, as shown on the map, was of prime importance. He also agreed with the previous speaker that changes in the currents and position of sandbanks consequent on the gradual filling-up of the Silurian sea might explain the slight changes in lithology, without recourse being had to extensive alterations in the Silurian geography.

The PRESIDENT (Dr. J. W. EVANS) thought that normal faults parallel to the strike of Caledonian folding should not be described as 'Caledonian' faults, for they did not result from the same cause as the folding. It was interesting to note that the latest faults in the area dealt with had a north-and-south strike, while the latest faults between the Pennine Range and the valley of the Dee had a north-north-west and south-south-east strike. He suggested that both were of Tertiary age.

Mrs. Woods thanked Mr. Wedd for his remarks, and regretted that Miss Crossield and she had not been able to work on the

Carboniferous Limestone.

In reply to Prof. Boswell, she stated that she had used the term 'Caledonian' faults, because she believed that the faults in question had all been caused originally by Caledonian movements. That the faults in the south belong to the same series seemed to be proved by the forking of the Y Fron-werth Fault, all the faults north of it trending north-east and south-west, and all those south of it southeast and north-west. Traces of current-bedding had certainly been noticed; but she could not think that the double rhythm in the deposition of the *M.-nilssoni* beds could be due to that cause, as the thickness of each band remained the same throughout.

In reply to the President, she expressed her belief that the north-and-south faults were probably of much later date than the

others.

^{- 1 [}This term has since been discarded by the Authors, in the course of revision of the paper.]

8. The Geology of Sierra Leone. By Frank Dixey, D.Sc., F.G.S. (Read November 8th, 1922.)

[PLATES XII-XIV.]

CONTENTS.

CONTENTS.	
I. Introduction II. The Older Schists and Gneisses	Page 195
 (a) General Description. (b) The Amphibolites and Hornblende-Schists. (c) The Tale-Schists. (d) The Charnockitic Rocks. 	
(e) The Quartz-Magnetite-Schists. (f) The Tourmaline-Schists.	
III. The Granites and Granite-Gneisses	201
 (c) Petrography. (d) Inclusions within the Granites. (e) Associated Igneous Rocks. 	
IV. The Rokell River Series	
V. The Saionia Scarp Series	213
VI. The Basic Igneous Rocks (a) General Description.	214
(b) Petrography of the Dolerites.	
VII. The Plateau Sands and the Pleistocene and Recei	nt
Deposits	
VIII. Bibliography and Summary	218

I. INTRODUCTION.

The territory of Sierra Leone in British West Africa comprises a Colony and a Protectorate, covering a total area comparable with that of Ireland. The Colony consists mainly of a mountainous peninsula about 25 miles long and 9 miles in mean width. The Protectorate can be divided physiographically into a low-lying coastal plain, and an interior upland region composed of a series of broken plateaux [11]. The mountains of the Colony, rising abruptly from the seaward margin of the coastal plain, consist of a great noritic complex [9]. The main outcrop of the older schists and gneisses, as well as that of the Rokell River Series, falls entirely within the limits of the coastal plain [12]. The upland plateaux are composed of a group of great granite-masses, mostly younger than the schists and gneisses of the coastal plain [12]. In the north-western corner of the Protectorate, near Saionia, the southern

¹ The numbers in square brackets refer throughout to papers enumerated in the Bibliography, § VIII, p. 218,

margin of the great plateau of horizontal sandstone that extends over a large part of French Guinea runs for a few miles along the Anglo-French boundary [8].

II. THE OLDER SCHISTS AND GNEISSES.

(a) General Description.

The main outcrop of the older schists and gneisses extends along the coast of the Protectorate, from French Guinea to Liberia. It is extensively overlain by clays, sands, and gravels of Pleistocene and recent age; consequently, except along the beds of the larger rivers and on the flanks of low hills scattered over the plain, the

ancient basement-rocks are very poorly exposed.

In most respects these older schists and gueisses do not differ essentially from the corresponding rocks of other parts of West Africa, already described by various writers. They comprise many rocks which differ widely in respect of origin, composition, and age, such as hornblende-schist and amphibolites, tremolite-, actinolite-, and anthophyllite-schists, chlorite- and tale-schists, quartzmagnetite-schists, tourmaline-schist, epidote-schist, quartz- and quartz-felspar-schists, garnet-mica-schist, variable garnetiferous biotite-gneisses, hornblendic and pyroxenic gneisses, charnockitic rocks, and granulites. These rocks appear to represent an ancient series of arenaceous and argillaceous sediments, which was extensively invaded by basic and granitic magmas, and subsequently subjected to an intense metamorphism. Included among them are many composite gneisses, which have arisen largely as a result of the interaction of various magmas with pre-existing rocks. The basic intrusives, in the form of amphibolites and variable hornblendic and pyroxenic gneisses, now occupy large areas of the main outcrop of the older schists and gneisses on the coastal plain; while, among the succeeding granitic intrusions of the upland plateaux, they form the most abundant and characteristic representatives of the older rocks. Besides the amphibolites, many additional members of the older crystalline rocks appear locally as larger or smaller inclusions within the granites, and there is reason to believe that, prior to the irruption of these granites, the whole area of the Protectorate was occupied by the ancient metamorphic rocks. Unmetamorphosed, or slightly metamorphosed, sedimentary rocks do not appear to exist among these older schists and gneisses.

The foliation of this group of rocks varies between north-west and north-north-west, and it is interesting to note that the following features also are all aligned in this direction:—the main outcrop of the group, the hills and ridges to which the more resistant rocks give rise, the noritic complex, and even the general trend of the coast-line. The foliation-planes generally dip at medium to high angles south-westwards and west-south-westwards: locally, however, they are vertical or steeply inclined

north-eastwards.

(b) The Amphibolites and Hornblende-Schists.

Amphibolites and hornblende-schists bulk largely among the older schists and gneisses, and appear to form the most important division of this group of rocks. They are well developed in the lower Great Scarcies River above Kambia, and in the lower Rokell River; they form the Ogra Hills near Songo Town, a great part of the Messeri Hills, the Boia Hills, and the Moyamba Hills. They are also widely distributed through the granite-gneisses and

granites of the Protectorate as dark basic inclusions.

The amphibolites and hornblende-schists show considerable variation in texture, degree of foliation, and composition. Quartz and plagioclase are generally present, but either one of these may occur greatly in excess of the other. The hornblende is usually accompanied by a pale-green pyroxene, which may sometimes exceed the hornblende in amount. Biotite occurs to a variable but slight extent. In some types hypersthene accompanies the other ferromagnesian minerals, while garnet is of frequent occurrence. Massive orthoclase-bearing types are well developed in North-Eastern Kennema District, the orthoclase being usually accompanied by plagioclase, sometimes by microcline, not infrequently by quartz.

Associated in the field with these hornblendic rocks, and possibly related to them in origin, is an interesting rock-type that deserves special mention (484, 650). When fresh, the rock is almost uniformly black; when slightly weathered, however, the felspars become almost white, and the rock itself assumes a pronouncedly spotted appearance. The spots are formed of numerous small black crystals or patches of hypersthene, which show up plainly against the white ground-mass of plagioclase. Green or brown hornblende and pale-green pyroxene may be associated with the granular hypersthene. The spots are 2 to 3 mm. long, elliptical to lenticular in shape, and arranged parallel to the foliation of the

rock

As in Northern Nigeria² and in the Southern Eyre Peninsula,³ an igneous origin may be ascribed to the majority of the amphibolites and hornblende-schists of Sierra Leone.

(c) The Talc-Schists.

Talc-schists are distributed throughout the whole area occupied by the crystalline rocks, and, while often occurring as large inclusions among the granite and granite-gneisses, they have been seen in several localities to cover a considerable area, and in such

² J. D. Falconer, 'The Geology & Geography of Northern Nigeria' 1911,

¹ The numerals in parentheses refer throughout to rock-sections in the collection of the Geological Survey of Sierra Leone.

³ C. E. Tilley, 'The Granite-Gneisses of Southern Eyre Peninsula (Australia)' Q. J. G. S. vol. lxxvii (1921) p. 98.

cases to have suffered invasion and disruption by the granites. In at least one important area the talc-schist is seen to be intimately associated with hornblende-schists, quartz-schists, and highly-foliated granitic gneisses, the whole invaded by large granitic intrusions [8]. This area, which includes outcrops of talc-schists many miles in length, extends from Mabonto in South-Western Koinadugu District eastwards as far as Mamansu, and south-eastwards as far as Makeli: that is, over a tract measuring 25 by 15 miles. The talc-schists generally possess a strongly schistose character, are mostly pale greenish-grey to dirty green in colour, and occasionally contain numerous small octahedra of magnetite or grains of blue tourmaline. They are almost invariably associated with a fine-grained lustrous hornblende-schist, and in several cases it has been possible to demonstrate a transition between these two rock-types. The outcrops are generally littered with blocks of quartz of a coarse granular and platy structure, ranging up to several feet in length. Good exposures of the talcschists of the Mabonto area occur at Rowaka, where the outcrop measures 70 yards across the strike; and at Kalmaro, east of Masombiri, on the Magboloko road, where the outcrop forms hilly ground, and extends for fully a mile and a half across the strike.

As examples of talc-schists which have been derived from rocks other than hornblende-schist may be quoted occurrences north of Tungia near the northern boundary of Kennema District (448), and at Kamiendo in Konno District (549), both of which afford microscopic evidence of having been derived from ultrabasic rocks carrying olivine and spinel. Generally, the talc-schists of Sierra Leone, like those of Northern Nigeria, may (for the greater part) be regarded as representatives of basic and ultrabasic rocks which have suffered metamorphism after having undergone con-

siderable decomposition.

(d) The Charnockitic Rocks.

Closely associated with the older schists and gneisses, and of intrusive igneous origin, is a series of rocks ranging from hypersthene-granite to norite, and bearing a great resemblance to the Charnockite Series of India. These rocks are not only developed along the whole of the coastal region of Sierra Leone, but they are continued also into French Guinea in the one direction, and into Liberia in the other; moreover, similar rocks occur on the Ivory Coast,² as well as in other parts of West Africa. From the richness in magnesium of many of these rocks, and from their close association with many other rocks also rich in magnesium, I have been led to suggest for them the establishment of a West African Magnesian Province [10].

The more acid rocks of the series are frequently coarse, and they

J. D. Falconer, 'The Geology, &c. of Northern Nigeria' 1911, p. 116.
 A. Lacroix, C. R. Acad. Sci. Paris, vol. cl (1910) p. 19.

may sometimes even contain patches of pegmatite. They are pale blue-grey, blue, and mauve in colour, when seen in the field; they consist essentially of orthoclase, accompanied by variable amounts of microcline and microperthite, oligoclase, and quartz, besides hypersthene and a little biotite. Micropegmatite is often a common constituent, together with a 'myrmekite' or 'quartz de corrosion': it occurs marginally around the more acid felspars, and also scattered through the finer constituents of the rocks; in addition, it is seen as more or less rounded patches in both the felspar and

the ground-mass.

The acid rocks pass progressively into basic types with decreasing quartz and acid felspars, and with increasing hypersthene, monoclinic pyroxene, and other ferromagnesian minerals; at the same time, they become dark grey or even black. As hypersthene increases, biotite and orthoclase diminish: but plagioclase increases, and becomes more basic. The biotite is generally in the form of small deep-brown shreds. Moreover, in the basic rocks green hornblende is often an important constituent, usually accompanied by a pale-green slightly-pleochroic pyroxene ('pigeonite'). This pyroxene does not often occur in association with the hypersthene. The hypersthene is locally altered to dark-green hornblende. Pink garnet is frequently present. Accessory minerals occur as follows, in order of importance:—rutile, zircon, magnetite, apatite, pyrites, and epidote.

Cropping out among the basic charnockitic rocks, and not differing greatly from them in appearance, is a rock consisting of dark-brown hornblende and biotite, accompanied by iron-ore and pink garnet. This rock possibly represents the ultrabasic end of the series, and may be compared with the ultrabasic rocks of the Charnockite

Series of India.

The charnockitic rocks occurring in the central and northern areas of the main outcrop of the older schists and gneisses possess a well-developed foliation; the folia vary considerably in texture and in the relative proportions of the constituent minerals. The charnockitic rocks of the area adjacent to the Liberian frontier, however, as well as those of the Lokko Mountains, have escaped most of this metamorphism; and, probably as a result of this, they show a less intense foliation, and in field-characters more closely approach the charnockitic rocks of the Ivory Coast and neighbouring areas.

(e) The Quartz-Magnetite-Schists.

Quartz-magnetite-schists cover a large area in North-Eastern Pujehun District, and occur also in other parts of that district, in Konno, and in the lower course of the Rokell River. A small dyke-like mass of quartz-magnetite-schist is enclosed in granite on the Lago-Panguma road, and a few small fragments of the same rock occur in the granitic area of Kamabanzi, in North-Western Koinadugu District.

The quartz-magnetite-schists of North-Eastern Pujehun District are exposed on the road running from Lalehum to Beribu. These schists are very dark, well banded, and of variable texture. They exhibit the following varieties, which, however, are not sharply marked off one from the other:—

(i) Very dense type (464). This rock consists mainly of magnetite, but it contains also a fair amount of hypersthene, some quartz, a little pale-brown augite, and a few grains of green hornblende. The bands vary in texture and in the relative proportions of magnetite, hypersthene, and quartz. The quartz is generally granular; it sometimes occurs as large plates, which are seen between crossed nicols to break up into a fine mosaic. Many small octahedra of magnetite are enclosed in the quartz.

(ii) Quartzose type (465). This type consists mainly of granular quartz traversed by parallel rows of magnetite-grains. Crystals of magnetite and of pink garnet, showing various degrees of idiomorphism, are embedded in the quartz, and a number of ragged parallel lenticles of bastite also occur,

apparently after hypersthene.

(iii) Intermediate type (466). This consists of interbanded magnetite and quartz, the two minerals being present in about equal proportions. The bands are generally somewhat ragged, and in places they are ill-defined. The magnetite shows local alteration to hæmatite. Rocks of this type sometimes contain a little untwinned felspar (495).

The rock from the Lago-Panguma road (near the 10-mile stone) much resembles type (i): it contains in addition, however, some orthoclase and some acid plagioclase (Ry 19a). Another rock (646) that closely approaches this type occurs near Limri, on the lower Rokell River; in addition to magnetite, hypersthene, and quartz, it contains much pink garnet, as well as a fair amount of decomposed untwinned felspar. The hypersthene shows alteration to bastite and hæmatite, the garnet to a yellow and red-brown translucent product, and the magnetite to translucent hæmatite. This rock, unlike any of the other quartz-magnetite-schists described above, was found in place among the older schists and gneisses, and was, moreover, foliated parallel with them. The quartz-magnetite-schist from Kamabanzi closely conforms to type (iii).

Hæmatite-schists have been recorded as occurring among the older gneisses of Liberia, and similar rocks occur also in French

Guinea,2 the Gold Coast, and Nigeria.3

(f) The Tourmaline-Schists.

Tourmaline-schists are known from only one locality in Sierra Leone, although tourmaline of similar habit and colour to that in the tourmaline-schists occurs as grains in some of the talc-schists and associated granites, as well as in concentrates of stream-gravels from several parts of the country. The locality in question is situated immediately north of Kania (Kaninia), about 25 miles south of Kaballa. The outcrop of tourmaline-schist, which is

¹ J. Parkinson, 'The Petrology & Physiography of Western Liberia' Q. J. G. S. vol. lxiv (1908) p. 314.

² A. Lacroix, C. R. Acad. Sci. Paris, vol. cl (1910) p. 19.

³ I. D. Felderger, The Goeleger for a filter of Newtonia 1911.

³ J. D. Falconer, 'The Geology, &c. of Northern Nigeria' 1911, p. 114.

about a mile wide where examined, occurs in a country made up principally of hornblende-schist and amphibolite, all abundantly invaded by granitic rocks. Tourmaline was not found in any of the neighbouring rocks, and it appears advisable at present to place the tourmaline-schists among the group of older schists and

gneisses.

The tourmaline-schists are variable in composition and texture; some types consist of granular dark-green to black tourmaline interlaminated with quartz and a little decayed felspar, while others are of coarser texture, with masses of fine compact tourmaline embedded in quartz. The laminated variety may be compared with certain rocks from the central crystalline area of Northern Nigeria, which consist of alternating ribbon-like bands of quartz and tourmaline.

III. THE GRANITES AND GRANITE-GNEISSES.

(a) General Description.

The later granitic rocks which make up fully half of the Protectorate of Sierra Leone belong to the great granite massif that includes the eastern part of Fouta Djallon, and extends eastwards across the Upper Niger territory into the Ivory Coast. The rocks of this great massif consist mainly of biotite-granites and granite-gneisses; those developed over a large part of Sierra Leone, at least, are rich in microcline. All these rocks are

traversed by countless dolerite-dykes.

In Sierra Leone the granites are developed over the greater part of that area which lies on the north-eastern side of the outcrop of the older schists and gneisses. They give rise also to a long narrow inlier, bounded almost entirely by sedimentary rocks of a later date, which extends from the lower Mabole River northnorth-westwards towards Mount Kofiu in French Guinea; the rocks of this inlier have suffered an intense metamorphism locally. The older gneisses are represented among the granites as innumerable inclusions, and as large masses in which the intrusive nature of the granites is generally obvious. The granites have, in most cases, suffered little disturbance since their consolidation, apart from mechanical deformation of varying intensity in certain areas and along certain lines. Locally, however, especially along the south-western margin of their outcrop, they have suffered considerable metamorphism in common with overlying sediments of the Rokell River Series; in such areas it has not always been possible to distinguish the later granites from certain of the older gneisses. The granites comprise many intrusions which differ widely in age, but there is reason to believe that in nearly all cases they are considerably older than the sediments of the Rokell River Series. This belief is supported by the fact that in all instances in which the base of the unaltered sediments has been seen in

J. D. Falconer, 'The Geology, &c. of Northern Nigeria' 1911, p. 88.

contact with the granites, the relations have clearly been those of ordinary unconformability. Nevertheless, it should be mentioned that, among the metamorphosed representatives of these sediments, there are certain gneisses, and in one locality also a granite, which may possibly bear intrusive relations to the sediments.

(b) Foliation.

The foliation exhibited by the granites as a whole varies considerably in character and intensity: it has been produced by various causes acting at different times. Also, the degree of foliation developed in any one mass may show great variation, so that an apparently massive type may graduate into a strongly-foliated type within a very short distance. In other cases, the foliation is such that it can be recognized only when a large area of the rock is exposed, whereas a hand-specimen of the same rock

may appear devoid of any parallel structure.

The gneissic banding and foliation of the granites is to be ascribed essentially to conditions that prevailed during the primary consolidation of the rocks.1 Features of true metamorphic origin are variously developed, and appear most commonly as mechanical deformations of different degrees of intensity; but sometimes considerable reconstruction has taken place. Moreover, since every gradation may be observed between these two effects of metamorphism, and since flow-movements within a partlycrystallized magma may produce various crush-structures, it is not infrequently almost impossible in the field to assign the parallel structure of a granite to any particular cause or age; indeed, two, or even three, intersecting parallel structures have sometimes been observed within the one rock-mass. It is obvious, for instance, that two such intersecting parallel structures may arise in a rock, if a shearing stress be applied to the partly crystallized magma in one direction, subsequent to the establishment of a primary flow-banding in another direction.2

Despite these difficulties and uncertainties, it is nevertheless of considerable interest to note how the average foliation of the crystalline rocks gradually changes in direction from one part of the Protectorate to another. For instance, over the western part of the country the foliation of the older schists and gneisses, and also of the later granites associated with them, varies in direction between north-west and north-north-west. In the north-western part, however, the foliation (when followed eastwards) is seen gradually to swing round north and south, and later almost to northeast; the north-and-south foliation prevails over a considerable area, which extends as far south as Kamabai. Finally, the foliation observed in almost the whole of the eastern part of the country varies in direction between north-east and north-north-east.

¹ See C. E. Tilley, Q. J. G. S. vol. lxxvii (1921) p. 95.

² See A. Harker, 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. Scotland, 1904, pp. 90-93.

Whereas, in the northern part of the Protectorate, the foliation swings round gradually from north-west to north-east, near the south-eastern corner, on the other hand, two distinct systems of foliation occur, running about north-west and north-east respectively; these two systems are sharply separated by a sinuous line that trends northwards as far as Boajibu (Kennema District), where it turns off north-westwards, and gradually dies out. explanation of this curious phenomenon may perhaps be found in the fact that certain forces have at several different periods produced various degrees of crushing and foliation in the rocks of the south-western part of the Protectorate, and also in the presumption that much of the north-easterly foliation of the granites of the east and south-east was produced by a shearing stress: these two systems of foliation, running more or less at right angles to each other, may thus be regarded as being in a sense complementary, if we assume, as appears probable, that they were produced largely by the same sets of forces. In the north, however, where the transition between the two systems is gradual, the effects of the force concerned were diffused over a considerable area; whereas in the south-east, where the transition is abrupt, they were confined within a relatively small area, and possibly also were more intense. The average foliation of the crystalline rocks of countries adjacent to Sierra Leone has been found by other writers to vary in direction when traced from one region to another.1

Narrow zones of crushing have been observed to cross the granite in several parts of the Protectorate [5], but they do not appear to be associated with faulting of any kind; the crush-planes in such zones are generally more or less vertical. At the Sewa Falls a series of gently undulating shear-planes traverse in a horizontal direction a granite that possesses a vertical foliation, and give to the rock, as seen from a distance, the appearance of being well bedded [12].

(c) Petrography.

On the whole, the Sierra Leone granites [5, 8, and 12] belong to the alkaline type, and nearly all of them are of the potassic variety; granites characterized by soda-felspars, soda-amphiboles, and pyroxenes have not been recognized. A large proportion of the granites are rich in microcline, and very few of them are free from this mineral; the microcline is accompanied by more or less orthoclase, by varying proportions of acid plagioclase, and by quartz. Micropegmatite is a common constituent: it occurs marginally around the larger felspars, interstitially, and also in small patches; moreover, small patches of graphically intergrown plagioclase and quartz are frequently enclosed in orthoclase, and patches of

 $^{^1}$ See P. Lemoine, 'Handbuch der Regionalen Geologie: vol. vii (Afrique Occidentale)' 1913, pt. vii, 6 $\alpha,$ p. 54.

microcline occur sometimes in the plagioclases. The plagioclases of the known rocks generally belong to the more acid varieties of the soda-line series, the twin lamellæ being narrow and faintly defined.

The ferromagnesian minerals are generally represented by a greenish variety of biotite; this mineral is sometimes accompanied by a little muscovite, and in other instances by green hornblende, or, rarely, by a pale-green pyroxene. Hornblende may replace the biotite in all proportions, but hornblendic granites are of much less frequent occurrence than the biotitic types. Among the accessory minerals, zircon and apatite are of common occurrence; rutile is often present as large and small grains, and epidotic minerals sometimes occur in considerable amount. In one case a rock (477) has been observed to consist essentially of quartz and epidote.

The granites vary in colour from pale grey to dark grey, and from pale pink to dull red; locally, they take on a dull greenish tinge, largely due to the development of epidote. Both as a whole and individually, they vary considerably in porphyritic character. A porphyritic granite that is extensively developed around and south-westwards of the source of the Niger is characterized by white tabular felspar-phenocrysts which are generally about threequarters of an inch long. In many other areas, phenocrysts of orthoclase range up to 21 inches in length. It not infrequently happens that the felspar-phenocrysts of a particular intrusion show every gradation between an almost perfect idiomorphism and a highly-fractured or even crushed condition; it would appear in many cases, as in the Makene Hill granite for instance, that this phenomenon originated as a result of movements in a viscous magma. A patchy appearance results when the phenocrysts differ in colour from the ground-mass, or when felspars of different colour are irregularly distributed. Several varieties of porphyritic granite possessing coloured phenocrysts strongly resemble the English Shap Granite, except that the colour of the Sierra Leone phenocrysts is of a deeper tinge.

The granites are cut by, or sometimes pass into, aplitic and pegmatitic varieties. The pegmatites of Sierra Leone appear to attain only a small development as compared with those of neighbouring countries; they are generally of smaller size, rarely more than 2 or 3 feet wide, and not particularly coarse [5, 8, and 9]. Syenitic modifications of the granites are of fairly common occurrence, whereas granodiorites and diorites occur much less frequently. The biotite-microcline-granites pass into syenites, largely by diminution in the quartz content; whereas the hornblendic granites pass gradually into syenites, through increase in hornblende as well as through decrease in quartz. Monzonite has been noted in several areas. Sphene is of more frequent occurrence in the syenites than in the granites. Tourmaline-granite has been observed only in South-Western Koinadugu District, between Masombiri and Magboloko, where it has invaded tale-schists. The tourmaline is of the blue variety, and occurs as scattered grains and as clusters of small prisms. A quartz-topaz-rock occurs near

Giehun, on the Pendembu-Kailahun road; it contains a little felspar, and apparently arises as a modification of a granitic intrusion [5].

(d) Inclusions within the Granites.

It has already been remarked that the granites of the Protectorate frequently enclose fragments of older gneisses and schists. The most characteristic and abundant of all these included rocks are the hornblende-schists and amphibolites (Pl. XII, fig. 2). In most cases these rocks do not show much evidence of alteration as a result of inclusion within the granite-magmas, doubtless because they were already in a highly-metamorphosed condition. The effects most commonly observed that may be ascribed to thermal metamorphism by the granite-magmas are an increased granularity, a greater toughness and freshness, and the development of many small flakes of brown biotite; moreover, the hypersthene becomes subject to a brownish alteration along cracks, accompanied by the deposition of much iron-ore in the form of grains, microlites, and patches of dust. In other cases (as, for example, 546), the hypersthene becomes more or less completely converted into a green hornblende of patchy colour, which possesses an irregular extinction. It not infrequently happens, however, that the included fragments become so closely veined or even impregnated with granitic material that they suffer active disintegration, or become so plastic that they yield quite readily to the flow-movements of the magma; they then are drawn out into thin lenticles and streaks, and thus gradually lose their individuality in the foliation of a composite gneiss.

The evidence for the view that the xenoliths in granites represent pre-existing rocks rests in the fact that corresponding rocks have been seen in place among the older schists and gneisses, and that in many cases the intrusive contact of the granite and the older rocks can be observed; along such contacts it is easy to trace the disruption of large enclosed blocks into smaller fragments and then into lenticles and thin streaks. There can be little doubt that the great majority of the inclusions of amphibolite and hornblende-schist observed in the granite have originated in this way, even where the fragments are far removed from an outcrop of similar rocks. Moreover, the fragments are often foliated even when the enclosing granites are not, while veins of granite frequently run parallel and transverse to this foliation; invasion along the foliation-planes may result in a well-developed lit-par-lit injection. Finally, the fragments have in many cases been split off along their foliation-planes, and in such cases their long axes are generally arranged parallel with the flow-structure of the enclosing granite-gneiss. It should, nevertheless, be pointed out that some of the amphibolites enclosed within the granite-gneisses possibly represent the remnants of dolerite-dykes which have

See.C. E. Tilley, Q. J. G. S. vol. lxxvii (1921) p. 113.

suffered disruption and metamorphism subsequent to intrusion into a granite-mass. Amphibolites that have been produced in this way are recorded by Prof. A. Lacroix¹ from among the granites and granite-gneisses of French Guinea near the source of the Niger, and even in the granites of Sierra Leone there have been observed several dolerite-dykes, still recognizable, which show various degrees of deformation and reconstruction.

(e) Associated Igneous Rocks.

Among the granites and granite-gneisses exist various other igneous rocks which are, however, apparently of small bulk as compared with the granites themselves; many of the rocks thus

associated with the granites occur as separate intrusions.

(1) Granophyric granites and related rocks.—A group of granophyric rocks, which embraces granite, syenites, and graniteporphyries, is represented in several localities, particularly in the Kotohun area, a few miles west-north-west of Kamabai. The granophyres and granophyric granite-porphyries pass into granophyric granites and syenites respectively, with decrease in the proportion of interstitial micropegnatite. The granophyric granites are readily recognized in the field by their peculiar brecciated appearance, due to the presence of numerous broken and resorbed crystals of quartz and felspar. In the hand-specimen the felspars are generally seen to possess a strong zonal structure, an effect due to the marginal alteration of these crystals. The rocks vary in colour from dark grey to dull red, and they are also sometimes dappled with small dark patches of hornblende. In thin section the granites (as, for example, 426 b) and syenites (for example, 428) of this group are seen to consist essentially of quartz, microcline, orthoclase, a little acid plagioclase, and a variable proportion of interstitial graphically-intergrown quartz and felspar, both orthoclase and plagioclase. Patches of micropegmatite occur along the margins of the felspars, and also as inclusions within these minerals. The larger quartz-masses form coarse mosaics. Green hornblende is the principal ferromagnesian mineral, but it is accompanied by small quantities of biotite and of pale-green to colourless augite. Iron-ore, sphene, apatite, and epidote occur as accessory minerals. One granophyric graniteporphyry [426 a] shows numerous large crystals of quartz and felspar embedded in a brownish ground-mass of micropegmatite, both coarse and fine. In these rocks the large crystals, particularly of quartz, often possess deeply embayed and rounded outlines, an effect due to considerable resorption; in many cases, however, idiomorphic outlines can still be recognized. The micropegmatite of the ground-mass breaks up into angular sections when examined between crossed nicols; it contains small corroded crystals of quartz and felspar, and a little deep-brown hornblende.

¹ C. R. Acad. Sci. Paris, vol. cl (1910) p. 19.

Similar rocks to those of the Kotohun area are known from near Bandajuma (502) in Pujehun District, and near Sandaru (542) in Northern Pendembu District.

(2) Syenites.—A foliated hornblende-syenite covers a large area around Kaballa; when traced westwards it is seen to pass into a gneissose granite, in which the hornblende is replaced by biotite. The rock contains numerous phenocrysts of orthoclase, showing long axes more or less parallel with the flow-banding. The phenocrysts are rectangular, and they range up to an inch and a quarter in length; they are pink to white in colour, and on a weathered surface stand out in sharp relief. In thin section (Ko 5) the rock is seen to consist essentially of orthoclase and microcline, with a little perthite and acid plagioclase; it contains also a small quantity of quartz and some micropegmatite, besides green hornblende, colourless augite, and sphene.

The following syenites appear to exist as separate intrusions in

the granites:

- (a) Hornblende-syenite, Dunkawalia, about 12 miles south of Falaba.
 (b) Nepheline-sodalite-syenite, near Gorahun, in North-Western Pujehun District. In the hand-specimen this rock is coarse in texture, and mottled in pale grey and deep blue. In thin section (474) it is seen to consist mainly of perthite and an acid plagioclase approaching albite. Enclosed within the felspar are many large and small patches of nepheline, often associated with a little cancrinite. A considerable amount of sodalite occurs, often replacing the nepheline. The slide shows several large plates of magnetite which are more or less completely enclosed in coarse brown biotite; a few flakes of biotite occur elsewhere in the slide also. A narrow vein consisting of granular albite, sodalite, and a little cancrinite, traverses the section.
- (c) Cancrinite-syenite (507), Sumbuya. This rock contains plagioclase approaching albite, much hornblende, a little biotite, and a considerable amount of cancrinite. The cancrinite occurs mainly in the form of rounded grains, and associated with it are a few small patches of nepheline.
- (3) Quartz-diorite.—In the Wanje River at Bandajuma, Pujehun District, is exposed a group of rocks which range from hornblende-diorite through quartz-diorite to granodiorite. The more basic rocks consist of plagioclase, hornblende, and biotite; but the more acid varieties contain, in addition, a little quartz and orthoclase, and also a fair amount of sphene.
- (4) Gabbros and related rocks.—The only gabbro of ordinary type known to be associated with the granites in Sierra Leone is one that forms a small mass, probably intrusive, near Giehun, on the Pendembu-Kailahun road. This rock consists essentially of basic plagioclase and augite, together with a little biotite and some iron-ore; the augite shows much alteration to hornblende. Gabbros and related rocks are well developed in neighbouring parts of French Guinea north-west and north of Sierra Leone.¹

¹ A. Lacroix, Nouv. Arch. Mus. Hist. Nat. Paris, ser. 5, vol. vii (1911) p. 108.

An olivine-norite of an interesting type occurs in the lower course of the Mano River; it is probably intrusive in the older schists and gneisses. The felspar of this norite (483) is a basic labradorite, about equal in amount to the sum of the ferromagnesian minerals. The pyroxene consists almost entirely of hypersthene; it is frequently streaked and mottled with brown hornblende, as if this mineral were replacing the pyroxene. Olivine occurs as crystals enclosed within the hypersthene. The rock is remarkable for its content in green spinel, usually intergrown with hypersthene and magnetite.

Near the mouth of the Moa River occur certain rocks (485, 490) of unusual character, which may provisionally be termed 'alkaligabbros.' They consist mainly of basic labradorite, sometimes showing clear cross-twinning of the albite and pericline types, together with green hornblende and pale-green pyroxene; interstitial to the felspars are many large and small allotriomorphic crystals of cancrinite, associated with sodalite and a little nepheline. In one of the rocks (485) small pink garnets are developed. Magnetite, apatite, and rutile occur as accessory

minerals.

(5) Minor intrusions .- In addition to the dykes and small masses of dolerite that are found cutting the granites and older rocks in all parts of the Protectorate (see below, p. 216), there are a few minor intrusions, which include rocks of several types. The following examples will serve by way of illustration :-

(a) Porphyritic microgranite (366), Saionia. This rock consists of phenocrysts of acid plagioclase, set in a microgranitic ground-mass which

contains green biotite and granules of pale-green augite.

(b) Hornblende porphyry (332), Bassia, Great Scarcies River. This rock presents a sharp chilled margin to the granite; it is fine-grained and porphyritic. The phenocrysts consist of felspar and hornblende. The felspar-phenocrysts are mostly plagioclase, and many of them exhibit a beautiful zoning; the hornblende-phenocrysts are extensively chloritized. The ground-mass consists of small crystals of felspar, mostly orthoclase, hornblende, micropegmatite, and some chloritic matter.

(c) Hornblende-lamprophyre (vogesite) (438), Masombiri. In the hand-specimen this is a fine-grained, dark blue-grey rock, dotted with many phenocrysts of hornblende and felspar. In thin section it is seen to consist of a microcrystalline granular ground-mass, in which are scattered large corroded crystals of green hornblende. The ground-mass consists of orthoclase, a little plagioclase, green hornblende, and numerous grains of

iron-ore.

IV. THE ROKELL RIVER SERIES.

(a) General Description.

The Rokell River Series is a group of old sedimentary and volcanic rocks, typically developed in the bed of the Rokell River. It extends south-south-eastwards from French Guinea, and projects into the Sierra Leone Protectorate as a long triangular area, which terminates near Mano on the Taia River [5, 8, 12]. The series may be regarded as consisting of a lower

division, comprising coarse basal conglomerates overlain by tough felspathic sandstones, and an upper division which includes a great development of marls, shales, quartzites, and sandstones, and a thick series of associated volcanic rocks; in the Saionia area at least, the upper division rests with marked unconformity upon the lower. All members of the series are generally seen in a highly disturbed condition, especially as the south-western margin of the outcrop is approached. The dips are usually high, the beds being frequently vertical, or even overturned. The Rokell River Series belongs to the group of 'schistes et quartzites redressés' of H. Hubert, and may be compared with the Birrim Series of the Gold Coast.² In Sierra Leone the series has so far failed to yield any fossils; nevertheless, it is undoubtedly of very great age, since it is overlain in the Saionia Scarp with violent unconformity by a series of horizontal sandstones in which Monograntus sp. (? priodon) has been found.

Prior to the deposition of the Rokell River Series, the older schists and gneisses, as well as the later granites, had suffered very extensive erosion, so that the sediments as a whole were laid down upon all members of the crystalline complex. The surface of erosion, however, was a very uneven one, since in different localities various subdivisions of the sedimentary series are seen

resting upon the crystalline rocks.

The outcrop of the series is largely obscured by a thin covering of young sediments; but, fortunately, the formation is exposed in the beds of several rivers that cross the outcrop. Between the rivers almost the only representatives of the series that can be seen are occasional outcrops of certain resistant beds, such as the volcanic rocks, the quartzites, and the metamorphic equivalents of some of the softer rocks; these resistant beds give rise to interrupted lines of low hills and ridges that may be traced right across country, more or less parallel with the long axis of the main

outeron

The basal conglomerate is very variably developed in different localities, whereas the younger beds are more uniformly represented. For instance, in the Saionia area [8, p. 5], where the conglomerate attains its greatest development, it is well exposed in the lower part of the Saionia Scarp for several miles east of Saionia, and also in the adjacent low country. In the Rokell River, a few miles below Makump [12], on the other hand, it crops out only as a few large crags, in which a thickness of about 35 feet is indicated; while in several other areas it is entirely absent. The constitution of the conglomerate varies according to the nature of the underlying rocks: near Makump, Saionia, and Bassia, for instance, the beds are made up largely of pebbles of granitic rocks; whereas, near the confluence of the Mabole with the Little Scarcies River, they contain numerous pebbles of amphi-

La Géologie de l'Afrique Occidentale' 1920.
 A. E. Kitson, Ann. Reps. Geol. Surv. Gold Coast, 1916-19.

bolite, garnetiferous granite, and other rocks belonging to the series of ancient crystalline schists. It is important to notice that in this last area, but apparently in no other, the conglomerate contains also many pebbles of sedimentary rocks, including quartzites, sandstones, arkoses, and grits. Near Saionia and Makump the conglomerate contains boulders of granite exceeding 3 feet in length, and in other localities also the deposit is of a very coarse nature. Near Makump the conglomerate is dull green,

but elsewhere it shows reddish and purple tints.

As regards the upper division of the Rokell River Series, the marls, mudstones, and shales are found to maintain a fairly even character whenever they appear. They are usually pale grey or greenish-grey, but occasionally they are black; moreover, in some localities they pass upwards by alternation into purple and pucecoloured varieties, while in others they are mottled or spotted in green and purple, or in green and puce-colour respectively. These rocks locally contain seams and lenticles of sandstone that vary from place to place in colour, hardness, and composition; sometimes also they pass upwards by alternation into bedded sandstones and flagstones. Quartzites are represented in many localities as thin beds; sometimes, however, particularly towards the south-western side of the main outcrop, they form thick beds that can be traced across country for considerable distances. In the metamorphic areas the quartzites are closely simulated by crushed siliceous conglomerates. The quartzites frequently show pale-blue or blue-grey tints, but sometimes they are white or cream-coloured; they usually contain numerous minute grains of iron-ore, besides small quantities of mica, brown spinel, tourmaline, and zircon.

(b) The Volcanic Rocks and Associated Intrusives.

The volcanic rocks and associated intrusives crop out as a broad band, about 12 miles wide, which can be followed across country from Mano, through Malal and Wongkufu, to Kukuna on the Great Scarcies River. These rocks give rise to a line of hills that include, for instance, those south-east and north-west of Yonnibana and those near Malal and Wongkufu; of these, the Malal Hills rise to a height of about 700 feet above the surrounding country. The volcanic episode was apparently ushered in by the outpouring of thin flows of acid lava accompanied by unimportant beds of ash and débris; after a brief interval, these flows were succeeded by great accumulations of lava and pyroclastic rocks in which basic types predominated. The development of the volcanic series of the Taia River differs from that of the other rivers, in that the rocks exposed are representative mainly of the preliminary outbursts. Associated with the lavas, particularly the basic types, occur a number of basic rocks that were probably intruded in the form of sills a short time subsequent to the extrusion of the lavas. All these rocks are locally rich in epidote.

These volcanic and intrusive rocks are similar to those of the Birrim Series of the Gold Coast. Moreover, they bear a remarkable resemblance to the Ordovician igneous rocks of Wales in petrological character, in the order of extrusion, and in the nature of the associated sediments.

- (1) Rhyolitic rocks.—The acid rocks are essentially of a rhyolitic nature: various lithological types may, nevertheless, be distinguished among them; in many instances, however, the different varieties appear to pass gradually one into the other. Rhyolites that may or may not show traces of flow-structure can sometimes be recognized; but it is difficult, and in some cases impossible, to distinguish them from certain highly siliceous ashes. These ashes are made up of the finest rhyolite dust with a variable admixture of small broken felspar-crystals; they break with a smooth conchoidal fracture, yielding sharp-edged fragments in precisely the same way as flint. They are blue-grey on a fresh surface, but on weathering they assume green-grey and dull green tints, and slowly acquire a hard white crust. In appearance and field-characters these rocks are indistinguishable from the 'chinastone' ashes of North Wales 1; with the incoming of coarser material, however, they pass over into pale-grey and blue-grey ashes of normal type. At Kamabanta, on the Little Scarcies River, is developed a series of dark-blue to indigo rhyolitic ashes that sometimes show a faint wavy banding. Agglomeratic varieties have not been observed. With the admixture of argillaceous matter and a little arenaceous detritus, the ashes pass gradually into fine- and medium-grained sediments, such as are commonly associated with the volcanic rocks. The combined thickness of the acid volcanic rocks and associated fine-grained sediments is doubtless as much as several hundred feet in some localities.
- (2) Basic lavas and intrusives.—The basic group attains a thickness of at least 900 feet, and comprises extrusive and intrusive types between which it is not always possible to distinguish. These rocks are accompanied by various detrital and pyroclastic accumulations, and by a few lavas. The basic rocks show considerable variation in composition; they include quartz-andesite, andesitic basalt, basalt, quartz-dolerite, and dolerite, besides certain spilite-like diabases. Most of the rocks are finegrained in texture; in colour they range from black and indigo to various dull-green tints. The essential minerals are plagioclase and augite, with iron-ore in the form of magnetite, ilmenite, and pyrites; neither olivine nor rhombic pyroxene has been detected. The rocks are frequently porphyritic in augite and felspar; in some cases clots of coarse augite-grains occur, such as would be expected in extrusive rocks. Moreover, some of the more basic types (as, for example, 618) show dark fine-grained patches of

irregular size and form, which appear to represent portions that solidified more quickly than the remainder. Several varieties, particularly in the Wongkufu area, are highly vesicular; while a few of them are porphyritic as well. The vesicles, infilled with chlorite and calcite, are sometimes drawn out into irregular streaks. Some of the fine-grained vesicular rocks resemble the 'spilite-like diabases' of North Wales.\(^1\) Moreover, certain ellipsoidal masses of a fine-grained volcanic rock appear to represent pillow-lavas; they occur near Kukuna, on the Great Scarcies River, among a mass of altered argillaceous sediment. The greenish tinge so prevalent amongst these rocks is due to the presence of secondary chlorite and epidote.

(c) Metamorphism.

The Rokell River Series has suffered much disturbance and deformation; this has resulted locally in the softer beds being squeezed up against and around the harder beds, and in the production of a more or less regular cleavage. Also, thin beds and lenticles of sandstones in the shales have lost their original form. and now appear as irregular isolated lumps in a confused argillaceous matrix. As the south-western margin of the series is approached in the lower course of the Rokell River, however, cleaved beds are found to pass with surprising rapidity into glistening phyllites and then into soft silvery mica-schists; little by little these schists become harder, and pass gradually into pale banded gneisses [12]. Similarly, the coarse conglomerates of the Little Scarcies River, a short distance below its confluence with the Mabole River, can be traced from the normal state into a highly-metamorphosed condition; first the matrix and then the pebbles become schistose, and later, with increased pressure, all constituents are so squeezed up together that they can scarcely be distinguished. Finally, a micaceous, dull-green, highly-metamorphosed rock is produced, such that its origin would be almost impossible of determination from consideration of a single isolated specimen. Under somewhat different conditions, the same conglomerate can be seen to have undergone excessive crushing with local mylonitization, resulting in a rock that possesses a curiously irregular fracture and a highly patchy character with respect to colour, texture, crystallinity, streakiness, and schistosity. The volcanic rocks and associated ashes can also be followed through successive stages of crushing and shearing. until they pass into a highly-contorted green-grey mica-schist, consisting mainly of alternating lighter and darker lamine with thin streaks and lenticles of quartz; such schists make up Fintoma Hill, about 13 miles south of Batkanu, and Rotokolon Hill. 8 miles south-west of Batkanu. There was sometimes also observed an apparent transition from sediments of the Rokell River Series

¹ A. H. Cox & A. K. Wells, Q. J. G. S. vol. lxxvi (1920) p. 282.

into a gneissose granitic rock. Several small outcrops of granite were observed near Masimera, on the Rokell River; the contacts with the sediments were not exposed, however, and the field-evidence was not conclusive as to whether the granite was older or younger than the sediments, nor as to whether it had contributed in any way to the metamorphism of these rocks.

The following observations made near the south-western margin of the Rokell River Series indicate that there have been several epochs of intense dynamic metamorphism in this area, and that these epochs were separated by long intervals of undisturbed

conditions :--

(1) The ancient schists and gneisses are all highly metamorphosed.

(2) Granites containing blocks of this series have suffered metamorphism.
(3) Conglomerates at the base of the Rokell River Series that have escaped metamorphism are seen to enclose large undoubted fragments and pebbles of the older schists and gneisses of foliated and unfoliated granites, and also of quartzites, sandstones, and other sedi-

mentary rocks, some of which show metamorphic characters.

(4) All members of the Rokell River Series are seen to assume an intense metamorphic character as they are traced from east-north-east to

west-south-west.

It is important to notice that the various deformative movements all resulted in a north-north-westerly foliation, and also that, as the area considered is approached from the east-north-east, relatively small zones of dynamic metamorphism are seen to occur in the Rokell River Series with increasing frequency and intensity.

V. THE SAIONIA SCARP SERIES.

The Saionia Scarp Series of Sierra Leone is identical with the 'grès siliceux horizontaux' of neighbouring parts of French In Sierra Leone the series is developed only in the Saionia Scarp, from which it takes its name (Pl. XII, fig. 1). This scarp, running about due east and west a short distance north of Saionia, forms one of the boldest physical features of the Protectorate; rising to a height of about 2300 feet above sea-level, it overlooks the great coastal plain that extends southwards to the sea over a large part of this country. The whole of the upper part of the scarp is made up of the sediments of the Saionia Scarp Series and a great sheet of coarse dolerite; these rocks together give rise to a great upper cliff nearly 1000 feet high. The series rests everywhere with strong unconformity upon all members of the Rokell River Series and upon all older rocks. The surface of erosion upon which the sandstones rest is, on the whole, of very low relief, and it is thus to be contrasted with that underlying the Rokell River Series.

The Saionia Scarp Series consists at the base of a coarse pale arkose which has a slight greenish tinge; this rock is succeeded by white to grey felspathic sandstones, which pass upwards by

¹ H. Hubert, 'Carte Géologique de l'Afrique Occidentale 'Paris, 1919.

alternation into blue-black flaggy mudstones. The series, including a dolerite-sill near the base, attains a maximum thickness of about 600 feet; it is overlain by a great sheet of dolerite about 300 feet thick, which apparently transgresses in a north-easterly direction from the horizontal sandstones on to the underlying crystalline rocks. This sheet extends northwards for a considerable distance, and forms the great Talla Plateau mentioned by Scott-Elliot [2].

The sandstones of the Saionia Scarp Series, like those of Fouta Diallon, frequently show strong current-bedding, and locally they contain thin beds of coarse grit and conglomerate; moreover, beds rich in chert, jasper, and chalcedony are sometimes associated with the sandstones. From the information at present available, however, it would appear that flaggy mudstones and other finegrained sediments are much better represented in the Saionia area than in neighbouring tracts 2; nevertheless, even in this area they greatly diminish in thickness as they are traced east-north-east-The formation, as a whole, however, when followed in the opposite direction, is found to increase from about 400 to nearly 700 feet in thickness; moreover, at an even greater distance to the south-west, namely at Mount Kofiu, it is about 800 feet thick.3 The thickness of the series diminishes between Mount Kofiu and Konakry, where the beds consist essentially of coarse siliceous sandstones.

Although no fossils have been found in the Saionia Scarp Series, Monograptus sp. (! priodon) has been obtained from shales interbedded with the horizontal sandstones of Telemele,4 a few miles west of Saionia. Accordingly, following H. Hubert, 5 we may regard these sediments as being marine in origin and at least of Ordovician age, or possibly even of Cambrian age.

VI. THE BASIC IGNEOUS ROCKS.

(a) General Description.

Under the heading of 'basic rocks' I include the dolerites and basalts of the Protectorate, and also the great norite-mass that forms the Sierra Leone Peninsula [9]. There seems little doubt that these belong to the great series of basic rocks which Prof. A. Lacroix 6 has shown to be extensively developed over a large part of West Africa, including French Guinea, Upper Senegal, and the Ivory Coast; the rocks of this series are characterized by abundance of magnesian minerals, including olivine,

¹ H. Hubert, op. supra cit.

² R. de Lamothe, Bull. Soc. Géol. France, ser. 4, vol. ix (1909) p. 526.

³ J. Chautard, 'Etude sur la Géographie Physique & la Géologie du Fouta-Diallon' Paris, 1906.

⁴ J. H. Sinclair, C. R. Acad. Sci. Paris, vol. clxvi (1918) p. 417.

⁵ H. Hubert, C. R. Soc. Géol. France, 1912, p. 46; also op. supra cit. p. 7.

⁶ Nouv. Arch. Mus. Hist. Nat. Paris, ser. 5, vol. vii (1911) p. 112.

hypersthene, and a magnesian pyroxene. They are particularly well developed in Fouta Djallon and in other parts of French Guinea adjacent to the western and north-western frontiers of Sierra Leone. As in French Guinea, so in Sierra Leone, these basic rocks belong to several different eruptive epochs. frequently occur in the form of dykes; in the crystalline area they appear, in addition, as more or less horizontal sheets and probably also as small bosses, whereas within the area of the horizontal sandstones they appear mainly as sheets and as sills. In Fouta Diallon certain of the sheets trangress from the horizontal sandstones on to the underlying crystalline rocks. The sheets doubtless represent surface-flows in most instances, but it is possible that in a few cases they represent sills from which the overlying beds have been denuded. The view as to the different ages of the sheets that rest upon the crystalline rocks is based partly upon the relation which the sheets bear to the various stages in the erosion of the crystalline massif. instance, Bintumane Peak, rising to a height of over 6000 feet above sea-level, is surmounted by a cap of dolerite which forms but a very small remnant of an ancient sheet; whereas the 3000-foot plateau south of the source of the Niger yet retains many patches of a second great sheet, of different composition, that was not poured out until long afterwards. During the interval that elapsed before the irruption of this second sheet, almost the whole of the ancient Bintumane plateau had been worn down to the level of the lower plateau. In Sierra Leone these sheets have not been found to exceed 325 feet in thickness; but in neighbouring parts of French Guinea they sometimes attain a considerably greater thickness. Tuffs have not been observed in association with any of these dolerites. The dolerite of the thicker dykes and sheets is often very coarse in texture, and in such cases it may pass gradually into a typical gabbro.

With regard to the age of the dolerites, it should be noted that even the youngest of the various sheets overlying the crystalline plateaux had suffered extensive erosion prior to the accumulation of the Plateau Sands [11 & 12], and consequently the dolerites are unlikely to be of less than early Tertiary age, while they might possibly be considerably older. No trace has been seen in Sierra Leone of Quaternary and late Tertiary rocks, such as are

known from other parts of West Africa.1

There is no obvious reason why the huge mass of norite that constitutes the Sierra Leone Peninsula should not be regarded, in agreement with Lacroix, as belonging to the great basic series of French Guinea. If this be admitted, then the norite would doubtless form part of the older group of basic rocks. As supporting this view, it may be mentioned that the norite has

P. Lemoine, 'Handbuch der Regionalen Geologie, vol. vii: Afrique Occidentale' 1913, p. 52; also H. Hubert, op. supra cit. p. 12.
 Nouv. Arch. Mus. Hist. Nat. Paris, ser. 5, vol. vii (1911) p. 110.

been carved into several high plateaux, analogous with those of Fouta Djallon and the Saionia Scarp upon which the horizontal sandstones rest; and it appears highly probable, moreover, that these sandstones, which still extend as far south as Mount Kofiu, extended at one time as far as the Sierra Leone Peninsula also. Since the older basic intrusives of Fouta Djallon are known to be younger than the 'schistes redressés', but older than the horizontal sandstones, these observations should give some indication as to the age of the norite, concerning which it has not been possible to obtain any direct evidence. Since the horizontal sandstones are believed to be, in part at least, of early Palæozoic age, it is thus possible to suggest a well-defined minimum limit for the age of the norite.

(b) Petrography of the Dolerites.

It will be convenient to describe these rocks under the headings

of dykes and bosses and of sheets respectively.

(i) Dykes and bosses.—Intrusions of this type, particularly the dykes, are represented in all parts of Sierra Leone; in some localities, however, they are especially numerous, as, for instance, within a few miles of Bandajuma (Pujehun District), among granitic rocks, and also in the Taia River between Taiama and Mano, among the sediments of the Rokell River Series. The rocks may be subdivided into (1) quartz-dolerites, containing interstitial micropegmatite and orthoclase, and (2) olivine-dolerites.

Of the quartz-dolerites, a dyke at Toiso, Pujehun District (469), and a dyke at Gene, Mano River (478) are coarse ophitic quartz-enstatite-dolerites; a dyke at Njala, near Mano (R 42), and a boss at the foot of the Saionia Scarp (374) are coarse ophitic quartz-hypersthene-dolerites; also a dyke at Fodea, North-Western Karina District (356), and a dyke near Pundaru (562) are porphyritic quartz-hypersthene-dolerites, with phenocrysts of hypersthene. A dyke cutting metamorphosed sediments near Makonti, lower Rokell River (636), is a much decomposed coarsely-ophitic quartz-dolerite.

Of the olivine-dolerites, a dyke in the Taia River, near Mano (R33), and a dyke near Hangha, Kennema District (Ry 14) are typical, being fine-grained and porphyritic rocks, with phenocrysts of olivine, augite, and plagioclase in an ophitic ground-mass. A dyke near Lalehun, North-Eastern Pujehun District (463), is an intermediate type, being an ophitic olivine-enstatite-dolerite, with

much interstitial pegmatite and quartz.

(ii) Sheets.—The sheet forming the top of the Saionia Scarp (371) is a coarse ophitic quartz-hypersthene-dolerite. This sheet attains a maximum thickness of 325 feet near Saionia; it extends, however, over a large area of French Guinea north of the Anglo-French boundary, and forms the Talla Plateau. The sheet capping Bintumane Peak (561), the highest summit of the Loma

Mountains, is a coarse porphyritic hypersthene-olivine-dolerite. Small patches of porphyritic olivine-dolerite (556) are scattered over the 3000-foot plateau that extends between Durukoro (Southern Koinadugu District) and the source of the Niger; they indicate the former existence of a great sheet over almost the whole of the granite-plateau. The maximum observed thickness of the dolerite was 250 feet. The dolerite is, for the greater part, fine-grained and porphyritic, containing many phenocrysts and small patches of

clear plagioclase.

The quartz- and olivine-bearing types of dolerite respectively were not erupted in any particular order; in this respect, the dolerites of Sierra Leone and adjacent parts of French Guinea may be contrasted with those from certain other regions of West Africa, such as Northern Nigeria, in which dolerites and basalts of pre-Tertiary age are free from olivine, whereas those of Tertiary and later times are rich in olivine. The olivine-dolerite dykes of South-Western Liberia, however, have been found by Dr. J. Parkinson 2 to bear a great resemblance to those of Tertiary age occurring in Southern Nigeria.

The dolerites of the Saionia Scarp have induced certain metamorphic effects in the sandstones and shales with which they have come into contact. Some of the sandstones have been baked and caused to assume a columnar structure; others have first been brecciated, and then welded into a solid mass. The shales have frequently been baked red, and in some cases they have been reduced to laminated cherty and jasperine rocks. The dolerites, however, are not known to have induced any mineralizing effects in the ancient sediments of the Rokell River Series, which they traverse in some localities.

VII. THE PLATEAU SANDS AND THE PLEISTOCENE AND RECENT DEPOSITS.

The Plateau Sands and the Pleistocene and recent deposits of the coastal plain have already been described in earlier papers, and consequently it will not be necessary here to do more than make brief reference to these accumulations. The Plateau Sands consist of an uncompacted sandy formation, which is developed on the crystalline plateaux of the north-eastern part of the Protectorate; they are analogous in general field characters to the 'drift' of Northern Nigeria 3 (see Pl. XIII, figs. 1 & 2). The sands exhibit a series of terraces with a wide vertical range, which are believed to have been formed in the course of an intermittent uplift that has operated through late Tertiary times almost down to the present day. The field-characters of this

¹ J. D. Falconer, 'The Geology & Geography of Northern Nigeria' 1911, pp. 139 & 253.

² 'The Petrology & Physiography of Western Liberia' Q. J. G. S. vol. lxiv (1908) p. 313.

³ J. D. Falconer, op. supra cit. p. 196.

formation have been described in the final Report of the Geological Survey [12], whereas the question of its age and origin has been discussed in a paper on the physiography of Sierra Leone [11]. The deposits of the coastal plain have been carved into a series of terraces of marine origin, which are analogous in many respects to those of the Plateau Sands [11, 4, 5, 8, & 12].

In conclusion, I have much pleasure in acknowledging the assistance that I have received from many friends. I am greatly indebted to Prof. A. Hubert Cox, who kindly arranged for the accommodation of the Geological Survey at University College, Cardiff. All laboratory work connected with this paper has been carried out in his Department, and for the facilities thus given, as well as for valuable suggestions and criticisms in the course of the work, I wish to record my grateful acknowledgments. To my friend and colleague, Mr. A. E. Kitson, C.B.E., Director of the Geological Survey of the Gold Coast, I owe cordial thanks for permission to examine various specimens collected by his Department, and also for the great interest that he has shown, in the course of many discussions, in the progress of my work in Sierra Leone. To the officers of the various Government Departments of the Colony I am indebted for much assistance in the course of my travels through the areas that I have described, as well as for very many personal kindnesses. Finally, I would like to express my appreciation of the help extended to me by my wife, who cheerfully accompanied me through my second and third tours in the Colony, and in this and in other ways greatly facilitated my work.

VIII. BIBLIOGRAPHY AND SUMMARY.

[1] G. GUERICH, 'Olivin-Gabbro von Freetown' Zeitschr. Deutsch. Geol. Gesellsch. vol. xxxix (1887) p. 96.
[2] G. F. Scott-Elliot & C. A. Raisin, Col. Rep. Misc. No. 3 (Sierra Leone)

1893.

[3] J. S. SHAND, 'The Norite of the Sierra Leone' Geol. Mag. 1918, p. 21. [4] F. DIXEY, 'Pleistocene Movements in Sierra Leone' Trans. Geol. Soc. S. [4] F. Dixer, 'Pleistocene Movements in Sierra Leone' Trans. Geol. Soc. S. Africa, vol. xii (1919) p. 112.
[5] Id. Rep. Geol. Surv. Sierra Leone, 1919.
[6] Id. 'Lateritization in Sierra Leone' Geol. Mag. 1920, pp. 211 & 524.
[7] Id. 'Primitive Iron-Ore Smelting Methods in West Africa' Mining Mag. vol. xxiii (1920) p. 213.
[8] Id. Rep. Geol. Surv. Sierra Leone, 1920.
[9] Id. 'The Norite of Sierra Leone' Q. J. G. S. vol. lxxviii (1922) p. 299.
[10] Id. 'The Magnesian Group of Igneous Rocks' Geol. Mag. 1921, p. 485.
[11] Id. 'The Physiography of Sierra Leone' Geograph. Journ. vol. lx (1922) p. 41.
[12] Id. Rep. Geol. Surv. Sierra Leone, 1921.

Summary.

(1) About two-thirds of the area of the Protectorate of Sierra Leone is occupied by a series of granites and granite-gneisses; of the remaining area, half is made up of a group of ancient schists and gneisses, whereas the other half consists of a series of very old sediments termed the Rokell River Series.

(2) The older schists and gneisses represent a complex of highly metamorphosed sedimentary and igneous rocks. They comprise a great variety of rock-types that include amphibolites and hornblende-schists, tale-schists, quartz-magnetite-schist, and tourmaline-schist, besides a series of charnockitic rocks analogous to those of the Ivory Coast. These ancient rocks, particularly the amphibolites, frequently appear as inclusions of larger or smaller size within the later granites.

(3) The granites belong almost entirely to the potassic variety. The foliation of the gneissose type is ascribed mainly to movements that took place in the magmas prior to the crystallization.

(4) Associated with the granites are several other rock-types that are mostly of intrusive form; these associated rocks include tourmaline-granites, cancrinite-syenites, alkali-gabbros, and a

number of minor intrusions.

(5) The Rokell River Series comprises a lower division, consisting mainly of a thick development of coarse conglomerates which rest unconformably upon the crystalline rocks, and an upper division consisting of a great series of shales, marls, mudstones, sandstones, and quartzites. Interbedded with the upper division is a series of contemporaneous igneous rocks that comprises acid and basic lavas, besides a considerable development of rhyolitic ashes and tuffs. Associated with these igneous rocks is a series of basic intrusives closely related to the basic lavas. These volcanic rocks and associated intrusives are closely comparable with the Ordovician igneous rocks of Wales.

(6) The sediments and igneous rocks of the Rokell River Series are almost invariably seen in a highly-disturbed condition; they show every gradation between slight mechanical deformation and intense metamorphism, and the passage from one extreme to the other is often surprisingly rapid. These metamorphosed sediments are to be distinguished from those belonging to the

older schists and gneisses.

(7) The forces that produced the metamorphism of the Rokell River Series acted along the same lines as those that gave rise to

the ancient schists and gneisses of the same area.

(8) The southern margin of the great series of horizontal sandstones of French Guinea approaches the north-western corner of the Protectorate, and then runs for a few miles along the Anglo-French boundary, where it gives rise to the Saionia Scarp. The formation as developed in this area is termed the Saionia Scarp Series. On palæontological evidence the horizontal sandstones are considered to be of early Palæozoic age. The Saionia Scarp Series rests with great unconformity upon the Rokell River Series and upon the crystalline rocks.

(9) Basic igneous rocks are represented by the great noritic complex that builds up the Sierra Leone Peninsula, by a large number of dolerite-dykes intruded into both the crystalline rocks and the sediments of the Rokell River Series, and by sheets of basalt and coarse dolerite that rest upon the crystalline plateaux

and upon the horizontal sandstones of the Saionia Scarp Series. These basic rocks show great variation in age. They include quartz-dolerites and olivine-dolerites, and an intermediate type rich in hypersthene; they correspond to the great basic series described by Prof. A. Lacroix from French Guinea.

(10) The crystalline plateaux are overlain by an uncompacted sandy formation, called the Plateau Sands, which is in many respects analogous to the 'drift' of Northern Nigeria.

EXPLANATION OF PLATES XII-XIV.

PLATE XII.

Fig. 1. The Saionia Scarp, several miles east of Saionia.-The photograph shows the sandstones of the Saionia Scarp Series resting almost horizontally upon the upturned edges of the bedded conglomerates of the Rokell River Series. In the foreground is the inner margin of the great coastal plain, which here attains a height of about 400 feet above sea-level. In the middle distance, the scarp of the Rokell River conglomerates forms the edge of a wide platform upon which, set back at a considerable distance, the horizontal sandstones rest. At a point near the black crag shown on the right of the photograph, the conglomerates rest unconformably upon an ancient granite, and in the same locality the sandstones, transgressing from the base of the conglomerates, also come to rest upon this granite. The scarp of the sandstone series is clearly shown in profile on the left of the view; in the upper part of this profile it is possible to distinguish the scarp of the sheet of dolerite that caps the sandstones, whereas in the lower part may be seen the main scarp of the sandstones themselves.

2. Grey granite, with included blocks of hornblende-schist: Lago-Panguma road, Sierra Leone. The blocks of hornblende-schist are seen to be extensively veined, and in some cases more or less completely disintegrated, by the granite. In the vicinity of the inclusions the granite assumes a pronounced banded structure, whereas elsewhere it is practically free from

banding.

PLATE XIII.

Fig. 1. The sandy plains of Gahnia in North-Eastern Sierra Leone. The plains extend for a considerable distance northwards across the Anglo-French Boundary. The village of Gahnia is seen in the middle distance. Beyond it rises an isolated flattopped hill of sand (Plateau Sands) which rests upon an irregular surface of ancient granite.

2. Low hill of Plateau Sands banked up against a rocky granite-hill, near Kundukonko (South-Eastern

Koinadugu District).

PLATE XIV.

Geological map of the Colony and Protectorate of Sierra Leone, reproduced from the Report of the Geological Survey for the year 1921, by permission of the Secretary of State for the Colonies. Approximate scale: 32 miles=1 inch, or 1:2,027,520.

Quart. Journ. Geol. Soc. Vol. LXXXI, Pl. XII.

Fig. 1.—The Saionia scarp, several miles east of Saionia.



F. D. photo.

Fig. 2.—Grey granite, with included blocks of hornblende-schist, Lago-Panguma road.



F. D. photo.



Quart. Journ. Geol. Soc. Vol. LXXXI, Pl. XIII.

Fig. 1.—The sandy plains of Gahnia, in North-Eastern Sierra Leone.



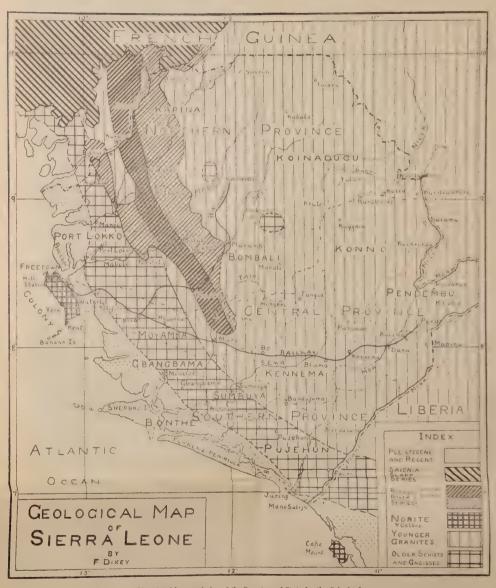
F. D. photo.

Fig. 2.—Low hill of Plateau Sands, banked up against a rocky granite-hill, near Kundukonko.



F. D. photo.





[Reprinted by permission of the Secretary of State for the Colonics.]



Discussion.

Prof. S. H. REYNOLDS commented on the resemblance between the charnockitic rocks of Sierra Leone and those of Southern India

and Ceylon.

Dr. J. W. Evans laid stress on the enlightened policy of the Colonial Office in promoting geological surveys in the colonies. Although the finances of the Protectorate of Sierra Leone had, in the absence of discoveries of economic importance, not permitted of the continuance of the survey, the Author had been able to trace out the essential features of the geology of the area. As Prof. Reynolds had pointed out, the geology presented a remarkable similarity with that of Southern India. The successive crystalline plateaux could also be paralleled in India: they were, in the speaker's opinion, to be attributed to continental agencies, such as alternations of temperature, chemical decomposition, and æolian action, rather than to marine erosion.

Mr. A. K. Wells remarked upon the variability in the degree of foliation of the granitic rocks, a phenomenon paralleled by the intrusive rocks of the Lizard, and explained by Dr. J. S. Flett as resulting from intrusion during alternating periods of stress and relief from stress. It would be interesting to learn whether the foliation of the Sierra-Leone rocks was an injection-foliation, and, if so, whether there was any evidence of changing stress conditions which could be adduced to account for the association of calcic rocks (including granites, syenites, and quartz-diorites) with such typically alkaline rocks as cancrinite- (originally nepheline-)

syenites and alkali-gabbros.

He pointed out that the Author evidently possessed the material for making an interesting contribution to the vexed question of the origin of the alkaline rocks. In the south-eastern parts of the Canadian 'shield' the batholiths of granite were frequently surrounded by a zone of strongly alkaline rocks, including nepheline-syenites of various kinds. Many American geologists, including Prof. R. A. Daly, favoured the view that the latter had arisen by the assimilation of the Grenville Limestones, into which the granite was intruded. In Sierra Leone there seemed to be no limestone available for assimilation, and a different explanation must be sought.

Major N. R. JUNNER remarked that one of the most interesting features of the geology of Sierra Leone was the abundance of igneous rocks -mostly of basic composition-rich in hypersthene and olivine, and sometimes garnet. In West Africa, rocks of this type appear to have their maximum development in the adjoining countries of French Guinea and Sierra Leone; they are known from the Ivory Coast, but are exceptional in the Gold Coast Colony,

and appear to be rare in Togoland and Dahomey.

Specimens of the lava and ashes of the Rokell River Series, which the speaker had the opportunity of examining, are almost identical in character with those in the Axim Series of the Gold Coast, and they appear to be similar to those described by Mr. Robertson from the Buem Series of Western Togoland.

A striking feature in the geology of this part of West Africa is the series of horizontal or very slightly disturbed sandstones to which the Saionia Scarp Series of Sierra Leone belongs. This series covers a vast area in West Africa, and rests with great unconformity on the presumably pre-Cambrian metamorphic rocks. Fossils are very rare in these beds, and the few that have been found suggest a Palaeozoic age. Monograptus (?) priodon has been obtained from shales in this series close to the Sierra Leone frontier, indicating an early Palaeozoic age. In French territory, according to M. H. Hubert, marine beds of Carboniferous age overlie conformably this series of horizontal sandstones. The Kwahu Series—sandstones, clay-shales, conglomerates, and limestones—of the Gold Coast, and the Oti Series of Western Togoland probably belong to the same group of formations.

The general characters of the series call to mind the description of the unfossiliferous flat-bedded sandstones of the Guianas and

the interior of Brazil.

Dr. H. H. Thomas, on behalf of the Author, said that he was sorry that the time at his disposal did not allow him to deal adequately with the comparisons and correlations of the Sierra-Leone rock-series with those of Nigeria and the Gold Coast; but he could assure Major Junner that these matters had been treated in the paper as completely as the extent of our knowledge would allow. With regard to the plateau-deposits, the Author had dealt with them but briefly, for his views on their origin had already been clearly expounded in the Journal of the Royal Geographical Society. In answer to Mr. Wells, the speaker stated that there could be no doubt that the foliation of the younger granitic series was of an injection character.

Postscript to the Discussion.

[On December 14th, 1922, Dr. J. D. FALCONER sent in the following contribution to the Discussion:—

He congratulated the Author on the excellent work that he had done in Sierra Leone, and regretted that the financial position of the colony had compelled the Author to transfer his activities elsewhere. From the account of the geology as presented, it would appear that the crystalline basement of Sierra Leone presented many similarities to that of Nigeria. Wholly or partly foliated granites, however, should not be termed 'younger granites,' that designation being already in use for non-foliated granites which, while absent in Sierra Leone, are extensively developed in Nigeria. On the other hand, the gabbro and norite phase of the younger intrusives, so marked in Sierra Leone, is inconspicuous in Nigeria. Nothing of similar age to the Rokell River Series or to the sandstones of the Saionia Scarp has yet been recognized in Nigeria. The superficial deposits of Sierra Leone can be compared with those of Nigeria, only if the former are of continental origin.

9. The Development of Leptoplastus salteri (Callaway), and of other Trilobites (Olenidæ, Ptychoparidæ, Conocoryphidæ, Paradoxidæ, Phacopidæ, and Mesonacidæ). By Frank Raw, B.Sc., F.G.S. (Read June 25th, 1924.)

[PLATES XV-XVIII.]

CONTENTS.

т	T. J. J. J. J. J. J.	Page 223
	Introduction	223
II.	Delimitation and Nomenclature of the Stages of Development in Trilobites	225
	The Development of Leptoplastus salteri.	
III.	The Material, its State of Preservation, and Mode of Study	227
IV.	The Ontogeny of Leptoplastus salteri Summary	$\frac{229}{242}$
V.	The Phylogeny of Leptoplastus salteri	248
	The Development of other Trilobites.	
VI.	The Ontogenies of other Olenidæ, and of Ptychoparidæ and Conocoryphidæ	257 265
VII.	The Ontogenies of Paradoxidæ	266 275
VIII.	The Ontogenies of Phacopidæ, and their Relation to Paradoxidæ	279
IX.	The Mutual Relations of some other 'Proparia' and 'Opisthoparia'	285
Χ.	The Ontogenies of Mesonacidæ	286
	The Facial Suture of the Mesonacidæ	301
XII.	Summary of the Ontogeny and Structure of the Mesonacidæ, together with their Phylogeny	306
TITX	Conclusions	309
	References	316
AL V.	TOTOLOGO	

I. Introduction.

THE above-named species of Olenid was first recorded in 1874 by Callaway 1 from the Shineton Shales of Shropshire, which he then claimed as of Tremadoc age.

It was described from imperfect material as a Conocoryphe, which name in 1877 he corrected to Olenus, giving at the same

time a description of the entire trilobite.2

A specimen for the first time exhibiting dorsal spines was in 1900 described by Dr. H. H. Thomas under a new name, Olenus

Callaway, 1874, p. 196.
 Id. 1877, p. 666.

mitchinsoni.¹ An additional occurrence of the species was in 1905 recorded by Prof. W. G. Fearnsides under the name of 'Parabolinella salteri'.² It occurred in the upper part of his Nant-ddu or Bellerophon Beds, which follow next above the Dictyonema Band north-west of Arenig Fawr, and it is there accompanied by Asaphellus homphrayi Salter and Parabolinella triarthrus (Callaway), which species are also associated with it at Shineton. In 1907 I briefly described its development, and assigned it to a new sub-genus 'Leptoplastides'.³ Finally, Mr. P. Lake redescribed it in 1919, under the name Leptoplastus salteri.⁴

It is now many years since, at Prof. Charles Lapworth's suggestion. I undertook the study of the trilobite fauna of the Shineton Shale. The first collection studied was that collected by Mr. Rhodes for H.M. Geological Survey, and lent to Prof. Lapworth by the then Director-General. Among these were several slabs covered with minute examples of the fossil in question, in different stages of development; and the early stages seemed so strange and unexpected that a special study was made of them. The result of this was presented at the meeting of the British Association in 1907, when a brief account was given of the ontogeny of the species as then determined. At the same time, reasons were adduced for separating it from Olenus and placing it under a new sub-genus. Furthermore, this ontogeny was interpreted as closely indicating the phylogeny of the sub-genus. Since then, other collections of Shineton fossils have been studied, kindly lent by the Sedgwick Museum, Cambridge, the Rev. W. K. Wyley, and Dr. T. T. Groom. For the extended loan of the Survey collection and these private collections I would here express my deep indebtedness, and tender my thanks.

Within these further collections were several examples of early stages of development, and I have been enabled to verify and extend my previous observations, and can now present more

extensive conclusions.

The surprising development of this species throws new light on the structure and development of other trilobites. Comparisons indicate, in my opinion, which characters are primitive; and these point to an origin of the Trilobite and, indeed, of the whole Euarthropod sub-phylum from the Polychæt worm. While this view has long been held by many zoologists, the nature of the relations between the Trilobite and the Annelid, as also the derivation of the one from the other, is now much more clearly indicated than has before been realized. Moreover, the characters of the deduced primitive Trilobite lead to conceptions of the points and lines of divergence of the various Arthropod groups from one another.

¹ Thomas, 1900, p. 619 & pl. xxiv, fig. 5.

² Fearnsides, 1905. p. 615. ³ Raw, 1907, p. 513.

⁴ Lake, 1919, p. 90 & pl. xi.

The intense interest of the ontogeny of this form and the stimulus of the comparisons that it offered with other trilobites and with other classes of Arthropods have led me very far away, though not unprofitably, I trust, from these Cambro-Ordovician trilobites. But the present paper deals only with the foreground of the vista that it opens up: namely, with the development, so far as this can be traced, of the more primitive trilobites.

II. DELIMITATION AND NOMENCLATURE OF THE STAGES OF DEVELOPMENT IN TRILOBITES.

The stages of development, in more or less complete sequence, have been described for several trilobites, notably by Barrande, Ford, Walcott, Matthew, Bornemann, and Raymond; but space does not allow of a general discussion here of the methods or results of previous investigations. They are reviewed below in connexion with the families concerned. The modes of subdivision of the development, their nomenclatures, and that adopted below require, however, a short discussion.

Barrande, to whom we still owe more than to anyone else our knowledge of the ontogeny of Trilobites, figures and describes in detail the development of Sao hirsuta Barrande, and of Dalmanitina socialis (Barrande), and of several others less completely. He divided the development of Sao into two periods, the line of division being that at which all the segments were acquired. This division was not instituted in Dalmanitina; for, whereas in Sao when the thorax is first complete, the pygidium also has already the full number of segments of the adult, in his Dalmanitina the pygidium continues to increase from 5 to 11 segments after the thorax is complete.

The first period Barrande subdivided into 'degrees' by each notable change of form represented in his specimens. These degrees, however, were quite arbitrary: for instance, his '3rd degree' had no free thoracic segments, and his '4th degree' had

two such segments.

Walcott, in describing the development of *Triarthrus becki*, adopted this term degree, but made it definite, the number of the degree corresponding with the number of thoracic segments.³

Beecher established the existence in several families of 'protaspis' stages preceding the development of free thoracic segments, and referred to them as 'larval'4. He also applied to the later development the terms nepionic, neanic, ephebic, gerontic, derived from post-natal human development. Of these the term nepionic is applied to the stages covered by Barrande's 1st period, less the protaspis stages; and the others—neanic, ephebic, gerontic—are loosely applied to different sections of

Barrande, 1852, pp. 387–403 & pl. vii.
 Ibid. pp. 552–56 & pls. xxvi, xxvii.

Walcott, 1879, pp. 26-28.
 Beecher, 1895, p. 169.

the second period. Though the protaspis is a larva, it is inadvisable to restrict to the protaspis stages the term larval, which applies equally to all stages short of the adult. It also seems inadvisable to apply to the later development terms which can have only a loose and purely theoretical application.

The protaspis does not satisfy the current definitions of a Trilobite, so it is certainly advisable to separate off the protaspis stages as a distinct period. But no further term is needed; we

can refer these protaspis stages to a Protaspid Period.

Regarding the later division (that is, between Barrande's two periods) it will be agreed that the subsequent development is properly divided in Sao, and that in other forms the development should be divided at a corresponding point; for the constant addition of segments before, and the entire lack of such later,

make a natural and important break in the development.

The addition of segments to the pygidium, however, is not of equal importance with the addition of segments to the thorax. Those of the pygidium are not fully functional, and so Beecher, in defining his 'nepionic' period made it coextensive with the addition of fresh segments to the thorax. In some species of trilobites the number of thoracic segments is probably quite indefinite, new segments being added to the thorax throughout life.2 But these are exceptions to the general rule, which is, that in Trilobites, as in all the higher Arthropods, the number of fully functional segments is early acquired. In most species of trilobites this number is already acquired when the individual has attained only a small fraction of the size to which it may grow: for instance, in Sao hirsuta this ratio is one-sixth,3 in Paradoxides bohemicus it is one-eleventh,4 in Leptoplastus salteri one-eleventh,5 and in Dalmanitina socialis one-sixteenth.6 And thus, if we make the division-line between the two later periods coincide with the completion of the thorax, we have in the latest period of development a very considerable amount of growth.

Three successive periods of development with fairly natural divisional lines can then be recognized. For these I shall use in the following pages the terms:—Protaspid, Meraspid, 7 and

Holaspid7 Periods.

The Protaspid Period embraces the various stages that precede the development of a definite transverse suture subdividing the

dorsal shield.

The Meraspid Period may be taken as beginning with the subdivision of the protaspis into cephalon and pygidium, and it covers the successive appearance of each of the thoracic segments.

The Holaspid Period covers the development after the com-

pletion of the thorax.

¹ Beecher, 1897, p. 98; 1900, p. 618.

Walcott, 1916, pp. 162, 164, 175, & 183; Burling, 1916, p. 54.
 Barrande, 1852, pl. vii.
 Ibid. pl. x.
 Below, p. 229.

⁶ Ibid. pl. xxvi, fig. 12 & pl. xxvii, fig. 15, pp. 552 & 554.

⁷ These terms were suggested to me by Mr. E. S. Cobbold, F.G.S.

As the thoracic segments seem to be added one at a time, the Meraspid period is divisible into definite steps. For these we can, following Walcott, adopt Barrande's term degree, and make it definite, characterizing each degree by the number of thoracic segments, and numbering it accordingly. The stage preceding that with one segment in the thorax (Degree 1): namely, that with no segment between the distinct head and the pygidium, would neither be a protaspis nor a typical Trilobite, and would thus lie between the Protaspid and the Meraspid Periods. Hence it could not be more appropriately designated than as Degree 0.

The Development of Leptoplastus salteri.

III. THE MATERIAL: ITS STATE OF PRESERVATION, AND MODE OF STUDY.

(a) State of Preservation.

The rock containing L. salteri at Shineton is a soft grev clay-shale. At a depth the trilobites which it contains probably all retain their dorsal tests. This holds good of a few of the specimens of adults, in which the brown test contrasts well with the grey rock-matrix. But in all the specimens of the earlier stages of development the integument has been entirely removed by solution, and is represented only by empty spaces in the shale. Indeed, the present investigation has only thereby been rendered possible, for this weathering has given the shale a tendency to split where the minute fossils abound. In this respect, the mode of fossilization is closely comparable with that which furnished to Barrande the larvæ of Sao. But the Bohemian matrix is much harder, and the fossils are easily seen and much more easily studied, owing to the deposition of bright yellow ochre (in marked contrast with the dark-grey rock) lining the spaces from which the integument has been dissolved.

The only Olenid ¹ that compares with it in regard to the degree of completeness of the development is *Triarthrus becki* Green, the development of which was described by Dr. C. D. Walcott, ² earlier stages being subsequently added by Beecher. In the American form, as described by Walcott, and so also practically in this from Shropshire, the stages of development are all represented from Degree 1 up to the adult; and, just as Walcott had to leave the protaspis to be found by Beecher, so I have to leave the discovery of the protaspis to another. The fossils again were found in shale; but the details of form are there beautifully preserved through the replacement of the integument by iron pyrites.

No such favourable conditions as those which obtain in Sao and Triarthrus exist in the present case, where the impressions are of exactly the same material and colour as the rock-matrix.

¹ See p. 261. ² Walcott, 1879, pp. 24–33 & pl. ii.

³ Beecher, 1895, p. 172 & pl. viii, figs. 12-13.

(b) Method of Investigation.

The earlier stages of development which present the features of greatest interest are very minute, and require to be considerably magnified; and, since the earliest stage measures less than a millimetre in length, the amount of detail that can be made out in these moulds or impressions of the integument is greatly limited by the texture of the rock, which, compared with the finest detail such as spines, is relatively coarse. Thus, owing to the mode of fossilization and the texture of the rock, the impressions of the early stages are very indefinite; and, as they show not the slightest colour, but only imperfect relief, their study under the microscope is very tiring, and it is exceedingly difficult to eliminate the personal factor. Hence the comparisons and deductions which follow have been based for the most part upon numbers of photo-micrographs, which, while greatly assisting the study, provide permanent records of the stages of development: records which are independent of any personal interpretation. It may be added here that, for these photographs, as well as for direct observation, external moulds have been found greatly superior to the moulds of the under side of the test; though in such a mode of preservation it is usually the moulds of the under side, showing as they do the natural convexity of the body, that are sought after, the others being often discarded. The superiority of the external mould as compared with the internal lies in the fact that it alone shows surface-ornament and axial spines, while it is also more clearly defined in other ways. Moreover, in a photograph it appears just as solid and convex as the others. Indeed, it is only by knowing the direction of the lighting by which the photograph was taken, or by its superiority in the above-mentioned characters, that one can detect that it is an external mould and not a trilobite in relief; and even then, as is well known, it is often only by a mental effort that one can see it correctly.

The development is especially seen in the gradual changes in the proportions of different parts of the organism, changes which are capable of exact expression by measurement. And as the dimensions, which appear in Table I (facing p. 242), furnish so important a part of the evidence for development, a few remarks on the mode of measurement will not be out of place. In photographing the different stages care was taken to magnify each by a definite multiple of 5, and the measurements have been made directly upon the negatives in transmitted light by means of a transparent scale. By having the graduations of the scale in contact with the photographic film the measurements can be made with considerable accuracy, and quite free from errors of parallax. The dimensions thus obtained, divided by the magnification, furnish the numbers given in the table; and, although there will always be a certain amount of error in the magnification, and consequently in the actual dimensions given, the proportion between the different dimensions of the same individual will be

about as accurate as the nature of the objects allows.

IV. THE ONTOGENY of LEPTOPLASTUS SALTERI. Periods and Degrees Represented.

Though very abundant material, embracing probably thousands of individuals belonging to this species, has been closely scrutinized, no example of a protaspis that could be attributed to this species has come to hand. Protaspids from Shineton Shale, belonging to three different species, have indeed been studied and photographed. One of them agrees closely with the early Meraspid degrees of L. salteri; but it is too large to fit that species, the part representing the future cephalon having already a length of '74 mm., as against '52 mm. in L. salteri in Degree 1. Also it fails to show any trace of the 'procranidial' spines, which are so characteristic a feature of the individuals in the early Meraspid degrees in L. salteri. It probably belongs to a contemporary large species of Olenid, possibly Parabolinella triarthrus (Callaway).

Degree 0 (zero) is also missing, and it is perhaps not without significance that among the larvæ of closely-allied forms not a single example of these very early stages has been described. The protaspis was evidently very small, and may have been ex-

tremely thin-shelled.

The earliest stage known belongs to Degree 1 of the Meraspid series. This measures 1.0 mm. in length (Pl. XVI, fig. 1). From this upwards all the degrees (except Degree 8) have been met with up to Degree 12, which, as 12 is the number found in the adult, falls in the Holaspid series. This number is already attained in an individual $5\frac{3}{4}$ mm. in length by $4\frac{1}{2}$ mm. in breadth, the increase in length throughout the Meraspid Period being 5.9 times.

The largest individual known to me is represented by the pygidium and a thoracic segment (Pl. XVIII, fig. 24), and is computed to have been 62 mm. long. This gives an increase in length during the Holaspid Period from $5\frac{3}{4}$ mm. to 62 mm., or of 10.8 times. There is thus throughout these two later periods an

increase in length of 5.9×10.8 , or 64 times.

Accompanying this growth there is continuous development in the proportions and shapes of the different parts; and, although the changes are so great, they are constant and gradual without any break. On the other hand, the rate of development of form is very different from that of growth in length. Measuring the first by the second, the rate of development of form is at first very rapid, but during the later growth very slow: the period of more rapid development roughly coinciding with the Meraspid Period, or period of segmental acquisition, and that of slow development with the Holaspid Period. The earlier period was doubtless much the shorter: it covers an increase in length of 6 times as against 11 for the later period, and, since there is reason to believe that it was a period of much more rapid growth, the ratio of its duration to that of the Holaspid Period was probably very much less than 6 to 11. But within this Meraspid Period, as befits a larval period, there is compressed much the larger part of the development of form.

Meraspid Period. Degrees 1-3. (Pl. XVI, figs. 1-6.)

The earliest stages are most frequently incomplete, often lacking the pygidium and failing to show any free cheeks. All the Geological Survey material, though furnishing beautiful examples, failed to disclose any that were not imperfect in these respects. It will be well, therefore, to take the general characters of these earliest degrees together before considering their slight special distinctions.

The majority of the individuals present a prominent head-shield, to which are attached the one, two, or three less clear thoracic segments, and an indistinct pygidium, when this is present. (Pl. XVI, figs. 2 & 3.)

Cephalon.—The cephalon is about equal in length to the rest of the body. It is deeply trilobed by the axial furrows into lobes of about equal width. In the absence of the free cheeks the head appears quadrangular, and the anterior and posterior margins are fairly straight and parallel, though the anterior margin is slightly concave, and the occipital ring projects strongly behind. The lateral margins in their posterior half are bowed outwards, their lines being then continued forwards and inwards to the ends of the anterior margin, which is shorter than the posterior.

At the anterolateral and posterolateral angles are straight sharp spines each about one-third as long as the head-shield, extending out in the shale in the plane of lamination, the anterior pair making an angle of 60° to one another in front, while the posterior pair make about the same angle behind. The anterior spines are robust, conical, and circular in section; while their bases are apparently just within the anterior margin of the cephalon, which at each end descends beneath them. From the front of the glabella on either side they are as distant as the width of the latter. The posterior pair are, except at the base, exceedingly slender; and they correspond exactly in position, size, and direction with the succeeding pleural spines of the segments of the thorax and pygidium. From the backward projection of the neck-segment also, there proceeds a strong spine directed upwards and backwards; but this, on account of its direction, is only visible in external moulds.

The prominent axial lobe is long and narrow, strongly convex from side to side, and descending towards the front, which it nearly or quite reaches. It is sharply defined by the axial furrows, and is of about the same width as the cheeks as these are usually preserved or exposed, the free cheeks not being visible. It is very clearly divided into an anterior longer lobe, and, counting the neck-segment, four subequal lobes behind this, the strong furrows running completely and almost straight across it.

The neck-ring, shorter at its sides than the glabellar lobes, projects behind, so as in the mid-line to be of the same length

as the other segments, and is produced into the above-mentioned backwardly directed spine, which is more robust than those of the

succeeding segments of the thorax.

The cheeks transversely are very convex, and across each from the middle of the anterior glabellar lobe runs outwards and slightly forwards a prominent ocular ridge, curving back at the point where it approaches the bases of the anterior spines to form the palpebral lobes, which terminate behind nearly opposite the anterior glabellar furrow. The eyes thus located are distant from the axial furrows by a space equal to that part of the glabella which lies between them. The posterior intramarginal furrows commence on either side of the occipital ring a little behind the neck-furrow, and run at first outwards and slightly forwards, then bending more forwards are lost apparently in the lateral margins of the head. No anterior marginal furrow is observable.

All the young head-shields first studied exhibited these characters, with two pairs of head-spines in addition to the

neck-spine.

Thanks, however, to the kindness of the authorities at the Sedgwick Museum, three individuals were found on a slab of Shineton Shale collected by the Rev. W. K. Wyley (Sedgwick Mus. 136), which showed the genal spines on the free cheeks, in addition to the two pairs of spines already mentioned. These individuals are in Degrees 3, 4, and 5 respectively. Later, several similar individuals with the same features have been observed in the Rev. W. K. Wyley's private collection which he kindly lent to me, one being in Degree 1 (W. K. W. 29 b). Our knowledge

of these earlier stages is thus rendered fairly complete.

In these individuals the genal spine is borne in its normal position on the free cheeks at the sides of the head-shield. In two of them (Degree 1, Pl. XVI, fig. 1, and Degree 3, Pl. XVI, figs. 4 & 5) the free cheeks are bent upwards upon the suture-line as a hinge, and thus brought into the same plane of shale as the fixed cheeks; in others one of the free cheeks has been almost detached, but just retains its connexion. The suture-lines run from immediately outside the posterolateral spines almost straight forwards and slightly inwards, then around the palpebral lobe to cut the anterolateral angle of the head-shield just outside the anterior spines. Both the anterior and the posterior spines, therefore, belong to the cranidium. The free cheek thus defined is triangular in form, between the suture (which forms the longest side) and the outer margin of the cephalon, which forms two fairly straight sides (the anterior somewhat the longer) about equally inclined to the axis of the trilobite. These meet in an obtuse angle from which the cheek-spine extends nearly in a line with the anterolateral margin, though it curves somewhat more outwards and then backwards. In Degree 3 it is perhaps half as long again as the anterior and posterior pairs of spines.

In these early degrees we find, therefore, three pairs of spines

in addition to the unpaired neck-spine, and the general shape of the head-shield is a broadened hexagon with approximately equal angles, but in which the posterior side is the longest, and the posterolaterals are the smallest. From the anterolateral and posterolateral angles spines bristle out, approximately bisecting the external angles, while from the outer angles curved spines project outwards and backwards, in continuation of the anterolateral sides.

From this description the cephalon of Leptoplastus in Degrees 1–3 will be seen to be closely comparable with those of Olenelloides armatus Peach, 1 and of an early stage of Olenellus gilberti Meek, 2 both of which have three pairs of lateral spines. Of O. gilberti, Walcott says: 'the antero-lateral spines are in the position where I should anticipate finding the termination of the facial suture in front of the eye'3; a remark justified for that particular stage 4 by the occurrence of just this relationship in our Tremadoc trilobite. But we can go farther, and can state that the two anterior spines are just within the facial sutures, forming the anterolateral corners of the cranidium. Similarly, the posterior spines form the posterolateral corners of the same; while the middle pair are borne on the free cheeks or 'pareïæ.'

As is pointed out in a forthcoming paper, these three pairs of spines are believed to have a high morphological significance, the anterior being interpreted as the pleural spines of the first dorsal segment, the posterior pair as the pleural spines of the sixth dorsal or occipital segment, and the middle pair as the combined pleural spines of the third and fourth. But, if they be morphological entities, we need morphological terms for them. At present no terms are in use, except the terms 'interocular' or 'intergenal' and 'genal' for the two posterior pairs. Neither of these terms, however, expresses the morphological position. The Mesonacidæ in which the intergenal spines are recognized are without a facial suture, so that the relation of these to the suture is not apparent; and the term genal is used, and is best retained for the dominant lateral head-spines whatever their morphology may be. Indeed, among the Trilobites, as shown below (pp. 281, 303), each of these pairs of spines persists in different cases as the dominant head-spines or genal spines. Their names should (if possible) express their morphological position; and, since they are seen to have a definite relation to the suture-line, a feature peculiar to Trilobites, the anterior and posterior being just within the suture at the anterolateral and posterolateral limits of the cranidium, and the middle pair being upon the free cheeks or pareïæ, perhaps it may meet with approval if I call them, in order from front to back, procranidial, parial, and metacranidial respectively.

¹ Peach, 1894, pl. xxxii, figs. 1-6.

Walcott, 1910, pl. xxxv, figs. 11–14 & pl. xliii, fig. 6.
 Ibid. p. 328.
 See below, p. 301.

Thorax.—The thoracic segment or segments are very long in a sagittal direction as compared with their shape in later stages, being in proportion much 'longer' than in the adult (the ratio sagittal length transverse width being, say, 0.16 for Degree I and 0.1 for Degree 12). The pleural extremities also are quite different from those of the adult, the pleuræ being abruptly terminated by their outer margin, which is about parallel to the axis, concave, and continued behind into long spines, reproducing almost exactly those of the posterior segments of Ctenopyge: for instance, Ct. flagellifer (Angelin), Ct. pecten (Salter), and Ct. bisulcata (Phillips).3 The axial lobe of the anterior segment following that of the neck-segment is bowed backwards; that of the posterior segment in Degree 3, however, runs straight across: each is somewhat broader than the extension of the pleura, and each bears a backwardly-directed median spine. The pleuræ are traversed by straight oblique furrows, running from the anterior margin on each side of the axis obliquely backwards to the pleural spine.

Pygidium.—This is nearly two-thirds of the length of the head-shield, and, without the pleural spines, is an equilateral triangle in form. It consists of segments of the same character as those of the thorax. The axis of five or more segments is somewhat less in width than the pleural areas, on which the pleuræ are indicated by well-marked oblique furrows like those of the thoracic segments, and by slender spines at least four in number on each side. The anterior pleuræ lie at right angles to the axial line; but successive pleuræ trend increasingly backwards, their spines, which in front are divergent, becoming at the back convergent (compare Ctenopyge tail ['thorax,' Brögger] and Parabolina tail). The axes also of at least the anterior segments bear backwardly-directed spines.

These Degrees 1-3, the general character of which has just been defined, not only differ from each other in the number of segments in the thorax and in size, but they show slight progressive development in the broadening of all the parts, and in the differentiation of the head-spines and of the glabellar furrows. We may briefly note their individual characteristics.

Degree 1. (Pl. XVI, figs. 1 & 2.)

The earliest degree is represented by two individuals:—a beautifully-preserved specimen in the Geological Survey Collection, lacking the tail and the free cheeks (Pl. XVI, fig. 2), and a complete individual in the Rev. W. K. Wyley's collection showing one free cheek half as wide as the fixed cheek and turned upwards upon the suture-line (Pl. XVI, fig. 1).

The cephalon is narrower for its length than in succeeding

 $^{^1}$ Linnarsson, 1880, pl. v, figs. 15–17. 2 Ibid. pl. vi, figs. 6 & 7. 3 Ibid. pl. vi, fig. 2

stages. It occupies, without the projection of the occipital ring, somewhat more than half the length of the body, the ratio of the head to the rest of the body being 6:5. The glabella is in this stage proportionately the narrowest for its length, and reaches the front of the cephalon. It is about equal in width to the fixed cheeks, is subcylindrical, but narrows to the front where it is rounded, and somewhat to the back, being somewhat narrower in the neck-segment and broadest in its middle segment. The glabellar furrows are strong, run almost straight across, and the anterior segment is half as long again as the hinder segments. The procranidial and metacranidial spines are long, equal in length to the width of the glabella, while the parial spines are only a little longer.

The single segment of the thorax has its pleuræ abruptly and

almost squarely terminated by the concave outer margins.

Degree 2. (Pl. XVI, fig. 3.)

This has only with certainty been found in the Geological Survey Collection, in an individual which lacks the tail and the free cheeks.

The cranidium is but little different from Degree 1, and the procranidial and metacranidial spines are long and sharp. The glabella is broader than the apparent width of the cheeks, and less cylindrical than in Stage 1, being narrowed more strongly to the front.

The thoracic segments present no fresh feature.

Degree 3. (Pl. XVI, figs. 4-6.)

Of this degree many individuals have been met with, mostly in material collected by the Rev. W. K. Wyley. In all, four

individuals have been photographed for special study.

The cephalon is slightly shorter than the rest of the body. It is now somewhat broader in proportion than in earlier degrees. Its axis is more conical, the occipital ring being now as wide as the two glabellar lobes immediately in front, and the glabella narrows to the front, which it does not quite reach, but leaves a distinct, narrow, marginal rim. The glabellar furrows, still complete across the middle, are deeper at the sides, towards which they curve distinctly forwards. The anterior segment is still as long as, or a little longer than, the others, and the eye-lines present the same character as in earlier stages. The parial spines shown very clearly by one individual of this stage (Pl. XVI, figs. 4 & 5) are now much stronger than the cranidial spines, and curve gently backwards. The free cheeks which bear these have increased in width.

The thorax and pygidium call for little comment. The individuals photographed show clearly the fairly straight spines given off from the pleure of the thorax and tail. They are clearly much longer than the pleure themselves, but cannot be

traced to their terminations because they become as fine as, or finer than, the texture of the shale. This is also the case with the head-spines in all these early stages. Two individuals (Ph. 26 & Ph. 5) show five rings in the axis of the tail, and two show four pairs of spines (Ph. 5 & Ph. 7). In Ph. 5, an external mould, the axis of the tail on the first three segments seems to bear axial spines like those of the thorax and neck (Pl. XVI, fig. 6).

Degree 4. (Pl. XVI, fig. 7.)

One example only of this degree has been observed and photographed. It differs little from the largest of Degree 3, its headlength is the same, but its body-length is greater. Being an external mould, it shows clearly the bases of several of the spines. The occipital spine is strong, but the axial spines behind it are not visible. The metacranidial are now small, though clearly seen. The procranidial appear to be represented by broad elevations, perhaps the bases of these spines. The right free cheek (on the left in the mould) is partly detached, and shows the strong curved parial spine. The glabellar furrows are continuous but oblique, as in the larger of Degree 3, and the anterior lobe is now no longer than the rest behind. The pygidium shows again four pairs of pleural spines.

Degree 5. (Pl. XVII, fig. 8, & left of figs. 9 & 10.)

At this degree, of which four examples have been observed and photographed (Ph. 9, 10, 12, & 27), in addition to the increase in size, an advance can be seen in the diminution of the cranidial spines, in the form of the anterior margin, in the glabella, in the shape of the pleural terminations of the thorax, and in the greater breadth of the pygidium. The head is now much shorter than the rest of the body, the ratio being as 5:7.

Cephalon.—The proportions of the cranidium are not much changed, but the anterior border in this and all later stages is more concave than hitherto. The eye-lines have the same anterolateral courses and the palpebral lobes are strongly marked, but the distance from them to the glabella, measured parallel to the eye-line, is now slightly less than the intervening width of the glabella. In front of the eye-lines and parallel to them are now developed the lateral parts of the anterior intramarginal furrow. The procranidial spines are robust, but much shorter than before; while the parial spines, now about as long as the glabella, are strongly curved backwards. The metacranidial spines, though clearly present, are not well displayed: they appear, except at their base, to have been very slender. The glabella is now wider in proportion, and does not extend so far forward, falling a little short of the marginal rim. The occipital furrow is as pronounced as ever, but now runs a little forward on each side to meet the axial

furrows. The glabellar furrows at the sides have attained their full obliquity and are here strong, but over the middle third of their courses they are very faint; while the anterior furrow throughout its course is fainter than those behind. The anterior lobe is now shorter than the others.

Thorax.—Here (as also in the pygidium) the segments are axially shorter for their transverse width than in earlier stages; and, while the posterior segments have the same form as before, like the posterior segments of Ctenopyge (Ct. pecten and Ct. flagellifer), the anterior segments are more obliquely truncated, the direction of truncation being continued in the pleural spines, on the inner sides of which the posterior margin is drawn forward as in the anterior segments of Ctenopyge flagellifer.

Pygidium.—This is slightly broader in proportion than in earlier stages, being obtusely triangular and rounded behind. In the character of its component segments it resembles earlier stages. The pleural spines of the pygidium are now of about the same length as these pleuræ themselves.

The anterior segments, perhaps the anterior three segments, of

the tail also bear spines on the axis (Pl. XVII, fig. 8).

Degree 6. (Pl. XVII, figs. 9 & 10, right.)

Two individuals in this degree have been noted and photographed. Both are well preserved. The smaller differs little, except by its larger size, from Degree 5. The other, slightly larger in size, agrees closely with the following Degree 7, and may well be described with it. The individuals of this degree exhibit in their dimensions the same progressive changes as those that are exhibited by Degrees 5 & 7.

Degree 7 (& large 6). (Pl. XVII, figs. 11-13.)

A beautiful individual in Degree 7 showing both free cheeks is contained in the collection presented by the late Dr. Charles Callaway to the Birmingham University (Pl. XVII, figs. 12 & 13). The head-length is now 0.37 of that of the whole body.

Cephalon.—The cranidium, as also the whole cephalon, is slightly broader in proportion than in earlier stages, such as Stage 3. The glabella shows this character more strongly still. It has still further retreated from the anterior margin, and there is now a continuous, strongly developed, anterior intramarginal furrow. The three glabellar furrows are now discontinuous, being represented by three pairs of oblique furrows, progressively fainter from the back to the front pair. The neck-furrow, on the other hand, is still practically as strong as ever. The ocular ridges are strong, and retain their somewhat forward course. The eyes are now proportionately nearer the glabella, being distant some-

what more than two-thirds of the width of the intervening part of the latter. The procranidial spines are still present as sharp cones directed forwards and outwards, approximately in the horizontal plane of the individual (Pl. XVII, fig. 11); but their length is only '075 mm. or only one-third of their actual length in early degrees. They can be seen to project from the middle of an outbowing of the cranidium which lies between the anteromarginal rim and the palpebral lobe. The metacranidial spines are also distinctly present, but as stouter and more obtuse cones than the procranidial. From just outside the metacranidials the suturelines run forwards and then inwards to the eye, curving especially in the posterior part of their course. In front of the palpebral lobe they run forwards outside and thus under the minute procranidial spines, and thence sharply inwards to cut the anterior margin of the cephalon.

The free cheeks, now about as wide as the narrowest part of the fixed cheeks, continue at their margins the anterior and posterior rims of the latter, and give to the sides of the cephalon contours which are approximately semicircular, though somewhat more sharply curved in the region of the parial spines. These proceed from about the same relative position as in earlier degrees and curve backwards, the whole spine, when the free cheek is turned upwards upon the suture into the horizontal plane, making an

angle with the axis of the trilobite of about 45°.

Thorax.—The seven thoracic segments are again wider in proportion to their sagitual lengths, and their pleural spines also are shorter in proportion. The lateral terminations of the posterior segments still resemble in general character those of the earlier stages, being obliquely truncated by sharp spines; but the posterior margins of the pleuræ just within these spines are somewhat drawn forward (like the anterior segments of Stage 5), making them slightly unguiculate. This character is increasingly pronounced towards the anterior segments, in which direction also the spines are directed more and more outwards. All segments bear also axial spines.

Pygidium.—This is somewhat broader in proportion, but closely resembles that of the earlier stages. In the two individuals in Degree 6 there are five and six segments respectively, while in that of Degree 7 there are seven.

The pleuræ end in backwardly-directed spines, nearly as long, measured from the front of each component pleura, as the length of that pleura itself. The first few segments of the tail (like

those of the thorax) all bear axial spines.

This degree is distinguished from earlier degrees by the shorter head- and body-segments, the more adult character of the glabella, the diminutive size of the cranidial spines, and by the further reduction of the pleural spines of the post-cephalic segments.

Degree 8.

No example of this degree has been noticed. From a comparison of the segmentation in earlier and later degrees it appears probable that at this stage the full number of segments exhibited by the adult (namely, 15) is already acquired (eight in the thorax and seven in the pygidium). The four anterior pygidial segments are thereafter liberated one by one into the thorax until the Holaspid stage is reached at 12 in the thorax and 3 in the pygidium. Only an imperfect rudiment of a further segment or two appears in later development, to be again reduced to disappearance in the adult.

Degrees 9, 10, & 11. (Pl. XVII, figs. 14 & 15, 16, & 17 respectively.)

These degrees do not differ much from one another, many of the characters of the adult having now been acquired. They can thus be taken together, although during these latest stages of the Meraspid Period considerable development of form as well as of size takes place.

Degree 9 is represented in my photographs by an individual from the Geological Survey Collection lacking only the free cheeks; Degree 10 by one complete from the Rev. W. K. Wyley's Collection; and Degree 11 by an equally perfect one from the Sedgwick Museum.

The cephalon differs but little from that of Degree 7. The glabella is broader in proportion, and the front of the glabella is less rounded, meeting the sides at an angle. Both of these characters are most marked in Degree 11, in which also the glabellar furrows are very faint. The ocular ridges, though less strong, are still prominent; but their courses from the glabella run less forward than before, and continue this change of direction with the successive degrees, the eyes shifting correspondingly farther back, and at the same time nearer to the glabella. The metacranidial spines are still present (at least in Degrees 9 & 10) as very short sharp cones, apparently continued into very fine spines. The procranidial spines have now almost disappeared, but two sharp eminences remain in Degree 9 (figs. 14 & 15) and perhaps in Degree 10 (left side, fig. 16). They cannot be seen in later stages, but the sharp angulation of the suture in front of the eyes, where it changes its course from forwards and outwards to a course almost parallel with the anterior margin, is clearly a relic of their former presence. It can now be observed that the anterior branches of the sutures, after leaving the programidial spines, run inwards in concave curves across the marginal rim, which they cut very obliquely and, continuing on each side over the anterior face of the rim, they meet below in the mid-line of the head at a very obtuse angle. This disposition is developing even at Degree 6, and characterizes the adults of Olenids in general.

The thorax presents a similar gradation of character from back to front as in Degree 7, and with its increasing number of segments continues to exhibit a progressive diminution of the proportional axial length of the segments. The pleural spines again are shorter, also the whole pleural termination is more unguiculate, and both of these characters are increasingly marked in successive degrees.

The pygidium consists of segments of the same characters as before, the component pleuræ being abruptly truncated by the outer margin continued back into spines. Its shape varies from obtusely triangular, rounded behind (Degree 9) to transversely semi-oval (Degree 11). The axis consists of six rings in Degree 9 to four in Degree 11, the last evidently incorporating rudiments of others. The 'limb' bears four or five pairs of points ranging, from front to back, from sharp spines into blunt teeth.

That of Degree 9 is more spinose than Degree 11: the former has three spines, a tooth, and a rudiment of a tooth on each side, and the latter two spines, one small tooth, and a rudimentary tooth. The first two segments of the tail show also some in-

dication of the presence of axial spines.

These degrees are transitional between Degree 7 and Degree 12, or the beginning of the Holaspid series. They cannot be contrasted in any character with the latter, except in their more spinose tail.

Holaspid Period: Degree 12. (Pl. XVIII, figs. 18 to 26.)

As no complete individual with more than twelve segments is known to me, this is assumed to be the number in the adult. It is met with in individuals having a length of $5\frac{3}{4}$ mm. and upwards. The largest parts of individuals indicate an estimated

length of over 60 mm. $(2\frac{1}{2})$ inches).

But, although the full number of segments may have been acquired in such small individuals, development in other respects still continues apparently up to the largest size known. This development affects especially the shape of the glabella, the strength of its furrows, the direction and strength of the ocular ridge, and the form of the tail-margin. The procranidial and metacranidial spines having now atrophied, there is in them no further development to be recorded.

The cephalon, at first quite like Degree 11, is later somewhat changed, especially by the migration of the eyes and of the parial spines. The glabella becomes (in the larger individuals) still shorter in proportion and more conical, also somewhat truncated, and finally concave in front. It progressively loses its furrows from before backwards, and is finally almost or quite smooth. The occipital furrow, on the other hand, is but little

affected. The occipital spine is now relatively much more slender. The ocular ridge in the smallest individuals of this stage is quite prominent, later it becomes very faint, and in the largest individuals is hardly discernible. Its course, at first somewhat forwards from the glabella as in earlier stages, gradually takes a more backward direction, finally sloping distinctly backwards in the larger individuals. Running as it does from the anterior lobe of the glabella to the front of the palpebral lobe, its change of direction is accompanied by a further inigration of the eye. such as has been seen to accompany the earlier development. eyes are reniform, very convex, apparently quite similar to those of Ctenopyge, and consist of numerous facets, beautifully shown in moulds of the under side of the eye-test (Pl. XVIII, fig. 25). In an individual 6.5 mm. long the facets are 025 mm. across, and in a larger individual of 8.7 mm, the facets though more numerous (about 300) are of the same size. The free cheek now attains its greatest development, being already in the smaller individuals of this period twice as wide, just behind the eye, as the fixed cheek of the same region. The parial or genal spine is now more posterior in position, being given off opposite the posterior lobe of the glabella. Its strength relative to the length of the head is little different from that of early stages, such as Degree 3.

In this, as universally in Olenids, the free cheeks are continued by the doublure to the anterior mid-ventral line, where they are separated by a median ventral suture (Pl. XVIII, fig. 20). This and the corresponding suture in the Asaphidæ may not improbably represent the two 'connecting sutures', as Barrande calls them (of, for example, Paradoxidæ, Ptychoparidæ, Calymenidæ, etc.), which appear to have migrated inwards till they have coalesced. The above-mentioned inward continuations of the free cheeks are partly dorsal, for the anteromarginal sutures which bound them have become dorsal in position, running outwards from the anterior margin in the mid-line obliquely across the marginal rim, and joining the anterior branch of the facial suture by a curve round

the position of the suppressed programidial spines.

The hypostome is often met with, sometimes attached to the free cheeks, but usually isolated. The one photographed (fig. 26) measures 0.6 mm. in length by 0.5 mm. in breadth. The general form is ovate, the broader end in front. It has strong relief, and is divided into two areas by a deep furrow:—an anterior and median ovoid elevation which reaches the front, and occupies nearly two-thirds of the length, and a broad convex border round the sides and back, widening somewhat to the back and narrowing to disappearance at the front on each side. At its inner boundary this rises abruptly to form a rounded crest, then descends more gently towards its periphery where it is flattened, to form a faint intramarginal furrow.

In their hypostomes the Olenidæ abruptæ differ little. This of L. salteri compares so closely with those of other Leptoplastus species, and of Acerocare, Eurycare, and Ctenopyge, that perhaps

no reliable differences can yet be instituted.

The thorax has now the full number of segments. These have the same proportions as in the preceding degree. Their pleural terminations also are at first unchanged, only the anterior being thoroughly unguiculate and passing back through abbreviated unguiculate to truncate. Gradually, with increasing size, the thoroughly unguiculate shape extends farther back, until in the larger individuals all the pleural terminations present that character, except those of the anterior segment, which, perhaps in connexion with its position next to the cephalon, in all the sizes has its pleure tapering to a point. All the segments retain their axial spines, which are long and strong, the hindmost one at least extending beyond the extremity of the tail more than three times the length of the latter.

The pygidium throughout is small in proportion, and consists of but three evident segments. In the smallest it is transversely semi-oval and rounded behind, but later it becomes truncated and finally emarginate behind. Though it bears at first a sharp tooth and one blunt tooth on each side, these gradually diminish until only the slightest evidence of the former presence of the anterior pair remains, and the tail is thoroughly entire. The axis of the tail no longer bears axial spines, unless one is present in the smallest individual, which shows a slight prominence on the anterior ring. Certainly, in the larger individuals, the tail bears not the slightest trace of these spines.

Of the three rings on the axis of the tail the hindmost in the smaller individuals is much the longest; and, as the number of rings in Degree 11 was five, it probably represents the two hindmost segments, the foremost passing into the thorax and the hindmost failing to be separately developed. This last was perhaps still more rudimentary in the largest individuals of this period, as in these the last axial ring is much smaller in proportion than before, and the posterior border of the tail is concave, with a

marginal rim behind the axis.

The smallest Holaspid individual photographed has an entire length of 5.7 mm. and a head-length of 2.0 mm. as against the 5.1 mm. and 1.8 mm. respectively of the individual (Sedgwick Mus. 127) in Degree 11, and is therefore probably only a little older. From this size upwards countless individuals are present on the slabs of shale examined, though very few are complete. This Holaspid Period includes a great increase in size, but the development of form is excessively slow.

Tables of Dimensions and Form-Ratios throughout the Development.

Dimensions of all the best individuals photographed, including representatives of all the degrees recognized, are set forth in Table I (facing p. 242). The individuals are arranged in the Q. J. G. S. No. 322.

order of their lengths of cephalon, which are measured from the level of the back of the cheeks to the middle of the anterior margin. Where a dimension is doubtful, on account of the condition of the

specimen, it is put in parentheses.

It may be thought that there is no value in the second decimal place of millimetres in these dimensions. But most of the photographs are of specimens magnified 10 to 30 times, and so these figures represent lengths easily estimated, by the use of which the ratios show a more natural gradation.

Except where the free cheeks are missing and the cranidium is clearly bounded, the width of the cranidium is difficult to measure; but, although inaccurate, this measure and the corresponding ratio are inserted, because, in the absence of the free cheeks, the measurement of the width of the cephalon is often impossible.

To represent the axial lobe of the head, the glabella is selected rather than the whole axial lobe, because, although the latter exhibits the change in proportion more strikingly, its posterior limit is less easily defined, owing to its extension in the occipital

spine.

By combining the dimensions in ratios, the changing proportions of each part are expressed in the lower half of the table. In both dimensions and ratios it may be noted that by 'length' is always meant the dimension in a sagittal or axial direction, and by 'width' the dimension across this, without reference to their relative sizes. Further, the ratios are all given as sagittal length

transverse width

Following the detailed Table I of Dimensions and Ratios, Table II is given, in which the average value of each ratio within each degree is expressed. Table II thus summarizes the results recorded in Table I. For the greater part each ratio exhibits in this table a continuous gradation from the first to the last degree. And, since six degrees are represented by only one individual each, and three other degrees by only two individuals each, there can be no doubt that, if we had a number of individuals in each degree sufficient to eliminate the effects of individual peculiarities and imperfections of preservation, each ratio would exhibit a continuous gradation from one end of the scale to the other.

Summary of Development. (Pls. XV-XVIII & text-figure, p. 249.)

The foregoing descriptions and measurements of the successive degrees being necessarily detailed, the development as a whole may now be considered and summarized.

Leptoplastus salteri presents itself in the stages of growth, from that characterized by one segment in the thorax up to the adult. The range in size is great, roughly from 1 to 60 mm.

THAT I. DIMENSION AND FORM-RATIOS OF TWENTY-THREE INDIVIDUALS OF LAGRANGISMS SHALL LANGING FROM FIGHT 1 to DESIGN 12.

No. of fig. in Plates XVI-XVIII. DEGREE (Thorax segm.)	24 (12 ?)	23 (12?)	22 (12 P)	21 12	14 12	19 12	18 12	17	16 10	14	12 & 13 7	6	9 & 10	9 & 10	8	7	3	.3		1 A =	2	3 1	1 1
Pygidial segments	3		3	3		3	3 (or 4)	õ (or 4)		6	(7)	б	5	6	5		5		5	(5)			te.
Dimensions in millimetres: Length of trilobite Length of cephalon Width of cephalon Width of crandium Length of glabella Width of glabella Length of thorax Width of thorax Length of thorax Length (sagittal) of an anterior therace segment Length of pygidium Width of pygidium	5·17	11'6 28 21'3 9'0 9'0 (21')	11 18°25 7°5 8°0 18 75 1°65 3°55 10°3	(7.54) (2.64) 1.86 1.8 4.52 .45 .54	2·27 6·26 3·8 1·6 (1·76—) 3·8 3·8	6'4 2'14 5'2 4'0 1'6 1'66 3'9 8'72 38 44 1'42	(5·73) 20 (4·7) 3.8 1·5 1·5 3·4 3·8 3·4 42 1·2	5·1 1·79 4·03 3·36 1·36 1·41 2·87 3·25 3·3 48 1·27	(3'8+) 1'47 3'35 2'56 1'1 1'02 (2'0+) 2*46 '26 ('32+) ('93)	3:16 1:2 2:13 9:1 86 1:57 1:88 27 36 82	3'04 1'13 2'45 2'0 '9 '83 1'42 1 97	2:4 :91 :1:53 :7 :65 :1:08 1:48 :40 :85	2:32 ·91 1:86 · · · · · · ·.	1.8 .8 1.25 .64 .50 .73 1.11 .15 .30	1.78 .73 	1.35 .59 .98 .61 .37 .6 .76 .76 .13 .25 .5	1·23 ·67 ·67 ·692) ·6 ·37 ·8 ·8 ·112 ·33 ·62	1·23 + ·57 ·83 ·49 ·34 (·38) ·76 ·13 ·33 ·6	1°23 °56 1°16 °89 °48 °85 °83 °83 °12 °37 °63	1°1 °5 °18 °43 (°36-) °7 °11 °29 (°5)	22 -4 -10 -25 -25 -25	2 7.6 3.5 2.7 11 1.7 2.7	140 140 14 14 14 1 13 13
Ratios: Cephalon: thorax: pygidium (sagit-																							
tal lengths)				100:20		150 182,21 1		100 , 16+, 27		100 - 131 - 30		101 118 13	100 110 46	100,91 19	160 93 , 38	100 83 45	16 53 63	100 67 58	5 100 59 6	200 00 00	Ica, 17	Des 28	100 20 61
Cephalon: width		*41		414	(*37)	'4	(*48)	144	'44		*46		(*49)						*4.9	-61	***		15.1
Cranidium : length width		'52	.80		*60	•52	'51	·53	*57	*56	•56	*63	***		*64	-6	(.62)	1.55	1, 1	***	1.2	1,1	15
Glabella : length width		1.0	*94	1.0	(.8)	*98	1.0	-96	1.1	1.1	1.1	1.1	1:3	1.3	1:3	1.4	1.4	1.4	1 1			1 4	17
Ant. thoracic segmt. : sagittal length transverse width		.09	.08	*10	.10	*10	.10	'10	*10	*13	*12	'12	*13	*14	.14	*15	.15	17	15	14	.*	2.	100
Pygidium: sagittal length transverse width	•39		'34	*34		·31	' 35	-38	(35)	•44	*42	'46	*49	*48	*52	.2	-53	:55	178	38			-
SPECIMEN No.	R.R. 2234.	R.R. 2268.	W.K.W. 25 a.	Callaway.	R.R. 2260.	W.K.W. 29 b. S	Sedgw. 136.	Sedgw. 127.	W.K.W. 29a	. R.R.	Callaway.	W.K.W. 296.	Sedgw. 136,	Sedgw. 136.	Sedgw. 136.	Sedgw. 136.	Sedgw, 130	Sed_8, 136	W K W 2	., 5 _ 4] .	In.	1. 1: 1151	W K W 200
Рното No.	(23)	(21)	(20)	(15)	(19)	(16)	(14)	(17)	(25)		(11) & (11 a)	(22)	(12) & (13)	(12) & (13)	(9)	rG.	15)	ī	20	1	2	1	1 :

TABLE II.—Some Form-Ratios in Leptoplastus salteri. Average Values in each Degree.

Degree.	12	11	10	9	8	7	6	5	4	3	2	1
Number of specimens averaged	6	1	1	1		1	2	2	1	4	1	2
Ratios: Cephalon: thorax: pygadium	100:173:21	100:160:27		100:131:30		100 : 126 : 43	100:114:44:5	100:92:48.5	100:83:45	100:60:60	100:42:	100:21 75
Cephalon; length width	*40	'44	'44			*46	(49)			.90		16:
Cranidium : length width	55	53	:59	56		'56	102	164	162	16.1	62	'67
Glabella : length	197	.96	1.1	1:1		1.1	12	1:3	1.1	1.1	1 6	1.65
Thoracic segment: sagittal length transverse width	1096	40	.10	.13		.15	-124	11	.12	.15	-16	·•)()
Pygidium: sagittal length transverse width	'35	:38	(:35)	.11		-42	475	.20	'50	156		16



The increase in length during the Meraspid Period is 5.9 times,

and during the Holaspid Period 10.8 times.

This growth is concurrent with the development of form, that is, individuals of the same length are in the same stage of their development in other respects. Thus, for example, in the individuals measured (with one doubtful exception) there is an increase of length for each additional segment in the thorax.

In marked contrast with the development of size, effected mainly in the Holaspid Period, the development of form is, for the greater part, effected in the Meraspid Period, although with

diminished force it continues to be active into old age.

This development of form, affecting as it does all parts of the body, we may consider under: (1) the general shape of the body; (2) the proportion between the different parts of the body; and (3) the form and details of these same parts.

The General Shape of the Body.

The general contour of the complete form in norma verticalis is influenced by the disposition of the free cheeks—whether they are in their natural position (that is, directed ventrally), or have been turned outwards into the main horizontal plane of the fossil. With the cheeks in their natural position the contour of the body is ovate, truncated at the front, and it is a noteworthy fact that from Degree 3 or 4, despite the increase in number of segments, the ratio of length of body to width of cranidium or thorax remains practically uniform at about 1.5 to 1, the increase in number of segments being counterbalanced by their continued relative shortening. This suggests that there was one definite proportion of length to width which was best suited to the conditions of life, and that these conditions did not alter very much during this development. Individuals with the free cheeks turned up into the main horizontal plane of the fossil present a further variation of form, owing to the change in shape of the free cheeks; but the ratio of width of head to length of body does not vary much.

This great relative shortening or widening of the segments is one of the most striking of all the changes that take place during development; it is illustrated by Table II, facing p. 242. It affects all regions of the body, and is most simply seen if we compare throughout the development the form-ratios of, say, a thoracic segment, or of the elements of the axial lobe in each division of the body: for example, the ratio of sagittal length to transverse width for an anterior thoracic segment diminishes from 0.16 in

Degree 1 to 0.10 at the beginning of Degree 12.

The Proportions between the Head, the Thorax, and the Pygidium.

The length-ratio of head: thorax: pygidium in Degree 1 is as 100:21:61, and in Degree 12 (early Holaspid) 100:186:21. Hence, for its twelve-fold increase in segments, the thorax increases

in length nearly 9 times as much as the head with its fixed segmentation. The increase of the thorax is held back by the diminishing size of the posterior segments; while, though the correspondingly opposite anterior segments of the head shrink so much, the development of brim and marginal rim makes up for this. As the above ratios show, the increase in length of the pygidium is only one-third as much as that of the head. This small increase goes with a reduction in the number of segments represented, but is chiefly due to a tendency to their atrophy (see p. 241). Within the Meraspid Period the head increases in length 3.9 times, the thorax 34 times, and the pygidium only 1.4 times.

Developmental changes in the head.—The head becomes continuously broader and shorter, as do all segments of the body. The convexity of both axial lobe and cheeks is very marked in the earlier degrees, in which in most specimens the free cheeks are hardly visible, being apparently directed downwards in what seems to have been their natural position. Dr. C. D. Walcott makes a similar observation relative to Triarthrus becki. In the adult, on the other hand, they are directed more outwards, and are not hidden in the same way. Comparing, however, those in which the free cheeks are turned 'upwards,' the outline at first (except for the projection of the neck-segment with its spine) is hexagonal (Degrees 1 3), the shape being clearly connected with the presence of the three pairs of spines at its angles—the pro- and metacranidial on the cranidium and the parial on the free cheeks. Of these seven spines only three persist to the adult: namely, the parial spines and the occipital spine. The two pairs of cranidial spines, at first apparently (Degree 1) about as strong as the parial spines, become in Degree 3 only about half the length and strength of the latter; but the cephalon (though relatively broader) does not differ much in shape. With the further reduction of the cranidial spines the anterior margin becomes concave, and the lateral margins convex. In Degree 7 the pro- and metacranidial spines are relatively insignificant, and the lateral margins of the head are practically semicircular, forming with the anterior and posterior margins a continuous curve, broken but slightly at the parial spines, which now make a more distinct angle with the anterolateral margin. Vestiges of the procranidial and the metacranidial spines still persist as late as Degree 10. The parial spines, coming off at first from a little behind the mid-length of the head, proceed in the adult from a somewhat more posterior position; at the same time, the margins of the cephalon, both in front and behind, extend towards the bases of these spines, and lose their circular outlines. These spines continue besides to maintain their relative size; and the occipital spine also, except for a narrowing of the base, persists comparatively unmodified to old age.

The marginal rim and its intramarginal furrow are at first only clearly developed along the posterior border. They extend some-

what farther in Degree 3, are well developed in front on each side of the glabella in Degree 5, and continuous round the front in

The axial lobe is at first long, cylindrical, and narrow, extending to the anterior margin, and narrowing to the back as well as the front. It is crossed transversely by four equidistant furrows; but the anterior lobe is distinctly longer than the others, an represents two somites. The axial lobe widens considerably in later development, especially at the back, becoming in the adult truncated-conical. This great widening doubles the ratio of width to length, and is thus considerably more rapid than that of the head as a whole. It is partly due to the progressive backward retreat of the glabellar front, which in Degree 1 reaches the front of the cephalon, but later retreats so as to leave in old age a frontal brim. Along with this the glabella in front becomes at first truncated, and later emarginate; while the anterior lobe loses the advantage of length which it had in early stages. . The glabellar furrows, at first strong and transverse, begin in Degree 3 to level up over the median line, and to become oblique. Full obliquity is attained in Degree 5; and in Degree 6 the central obliteration is almost complete. Henceforth the remaining parts of the furrows are gradually obliterated from before backwards, the glabella in old age being sensibly smooth. The occipital furrow, on the other hand, although like the glabellar furrows it changes its course somewhat, continues almost equally marked to the adult.

The eye-lines in Degree 1 issue from the mid-length of the anterior glabellar lobe, and extend outwards and somewhat forwards. This direction they keep up to Degree 7, but then swing backwards, so that early in the Holaspid Period they lie at right angles to the axial line, and in old age are directed as much backwards as in the earlier degrees they were directed forwards. At the same time, with the widening of the glabella, they diminish They also diminish in strength, being scarcely in relative length. discernible in old age.

Already in the earliest degrees the palpebral lobe is fairly prominent, and its position and form give to the eye an anterior position and somewhat anterior direction as compared with the The facetted character of the eye is well seen in the adult

in moulds of the lower surface of the test.

The dorsal facial suture in early degrees runs in a fairly straight line from front to back across the cephalon, just outside the bases of the procranidial and metacranidial spines. Behind the palpebral lobe it forms a slightly convex curve. In front of this it skirts the adjoining procranidial spine, and, turning abruptly inwards, is continued by the anteromarginal suture, which at the axial line is met by a median ventral suture.

Later, as the procranidial spines diminish, the antero-marginal suture, except in the mid-line, becomes distinctly dorsal in position; and, after the disappearance of these spines, the angle in the suture which marked their position becomes quite rounded, especially in old age. At the same time, with the migration of the eyes and the widening of the cephalon, the two branches of each facial suture come to be directed at right angles one to the other on either side of the eye, and at about 45° to the axial line.

With these changes the free cheeks alter in shape, and greatly

increase in area.

Changes in the thorax.—In the thorax two very striking and regularly progressive changes are observable in the character of the segments: one is the relative shortening of the segments in the axial direction, the other change is in the shapes of the pleural terminations. The former is discussed above (p. 243); the latter, namely, the change in the pleural terminations, may be illustrated by the characters of those of a normal segment,

say, the 2nd or 3rd in successive stages.

In Degrees 1 & 2 the pleuræ of the only segments are abruptly truncated by the lateral margins, which are parallel to the axis, concave outwards, and continued behind into long fine spines, as in the posterior segments of Ctenopyge. In Degree 3 the margin begins to be oblique, and the spines also are more oblique than before, as in the more normal segments of Ctenopyge. Further development seen progressively in Degrees 5, 6, & 7 consists in: (1) the continued shortening of the spine; (2) the increased obliquity of the lateral margin, until it is as oblique as, and then more oblique than, the spines; and correlated with this (3) the drawing-forward of the posterior margin just within the spine with the formation of a rounded notch; and (4) the rounding-off of the anterolateral angle, these various changes producing a straight sharp claw—the typical form in Parabolina. Changes in the same direction continue: the claw becomes more arched, better defined by the greater development of the hollow behind it, and is brought into a direction more oblique to the axis of the trilobite (Degree 9 onwards), as is characteristic of these segments in Leptoplastus and Eurycare. On the foremost segment, however, after Degree 6 (and in the largest individuals of Degree 12 on the second also) the claw is greatly reduced, and the pleura is short, tapering to an outwardly and somewhat backwardly directed point. This might be regarded as an adaptation to special mobility of the cephalon upon the first thoracic segments, a mobility greater than that which obtained between adjoining segments elsewhere in the thorax.

The progressive relative shortening of the segments affects all segments of the thorax about equally, those just added as well as those earlier present, but the form of the pleural spines in any particular degree is by no means so uniform. In all individuals except the youngest and the oldest (that is, Degrees 1-3 and the largest individuals of Degree 12), the anterior segments are the most advanced in the shape of their pleural terminations, and the succeeding segments are less and less advanced back to the

hindmost, which are most larval (ancestral) in character. the oldest segments always exhibit the highest development, and the newest segments the lowest, the stage of development of any segment according with its age. In the Holaspid Period, no new segments with their larval characters being added, even the hindmost segments gradually acquire unguiculate spines, until in old age all except the anterior have this character.

Axial spines are present on the thoracic segments in all degrees, and appear to maintain their strength throughout development. That on the hindmost segment becomes perhaps specially developed, and the largest individual exhibits this spine extending beyond

the back of the pygidium 3 times the length of the latter.

Changes in the pygidium .- Although the growth of this part is so slight, the other changes are as great or greater than those which obtain in either of the other regions of the body. These changes affect the general outline and the character of the external margin, the number of segments, and the dorsal spines.

In the earliest degrees the pygidium is triangular, but rounded behind; and it consists perhaps of six segments bearing pairs of pleural spines twice as long as the pleuræ themselves. Its individual segments are of the same form as those of the thorax, and like them they bear axial spines. In Degree 7 the number of segments has risen to seven. And in Degree 9, with the same number of pygidial segments, the full number of segments for the whole body is attained, for in Degree 11 there appear to be again In Degree 12 only three segments are defined on the axial lobe, the hindmost of which, being in the smallest individual of the degree fully twice as long as the segment in front, must represent at least two segments.

During development the pygidium becomes continuously shorter in proportion to its width, and becomes in turn obtusely triangular (Degrees 5-10), transversely semi-oval (Degrees 11 & early 12),

then truncated, and finally emarginate behind.

Its marginal spines shorten like those of the thoracic pleuræ; but here the shortening is later accompanied by a gradual suppression, advancing from back to front, the margin becoming perfectly entire in old age. In the later degrees the axial spines too diminish in number, the last being visbile on the front segment in

In fact, so long as the tail is furnishing fresh segments to the thorax, it consists of segments of the same character as those to which it is giving rise; but, when it has ceased to liberate segments, its own segments exhibit a degenerative development, beginning at the hindmost and advancing forwards, and become increasingly vestigial. In this its development is in marked contrast with that of the head and the thorax.

V. THE PHYLOGENY OF LEPTOPLASTUS SALTERI.

Division of the Development into Stages, and their Phylogenetic Significance.

The Heptacicephalic Stage.

The first three degrees of the Meraspid Period (or, at least Degrees 1 & 2, and the smaller individuals in Degree 3) agree in the great development of the pro- and metacranidial spines, in addition to the parial spine; and constitute a stage of the development. This, the earliest known stage, has already been likened to the Lower Cambrian Olenelloides armatus, and to the larva of Olenellus (Mesonacis) gilberti (p. 232). The agreement obtains, not only in the presence of three pairs of peripheral spines on a hexagonally outlined head-shield, but also in the elongated form and simple segmentation of the cephalic axis. In the postcephalic body also there is agreement with Olenelloides and with the typical segments of Mesonacis vermontana 1 in the axial length of the segments, and their short pleuræ, and to some extent in the form of the pleural spines. Further, in the smallest individual in Degree 3 the greater development of the pleural spines of the 3rd thoracic segment than of the others may possibly be related to the great development of the 3rd segment in these and other Meso-The eyes also present a peculiar agreement with those of Olenelloides, which differ from those of other Mesonacidæ in being both relatively concentrated in form and anterior in position. So striking and peculiar is the resemblance to this genus that we might well call this stage of development of Leptoplastus an Olenelloides stage. But this form, and indeed all the Mesonacide, are abnormal in having no facial suture; and in that respect, as inferred below, they are specialized. Also the above-mentioned forms have apparently lost their occipital and dorsal spines—another specialization, so that no Mesonacid could possibly be ancestral to Leptoplustus; and the relationship cannot be nearer than common descent from the same more distant ancestor.

Close comparisons can also be instituted with the Middle Cambrian genera Zacanthoides and Albertella; for instance, Z. typicalis Walcott² and A. bosworthi Walcott³ In these we note again segments axially long, having short pleura furnished with long straight spines; while axial spines are also present. In the heads of both we find an elongate axis with simple segmentation; and, while in Zacanthoides the anterior glabellar lobe is longer than the second (as in the earliest stage of L. salteri), in Albertella bosworthi it is actually subdivided into two segments. There are no procranidial spines in either form, but their loci are clearly indicated by the suture. On the other hand, metacranidial spines are well developed in Zacanthoides; but, like the procranidial, they

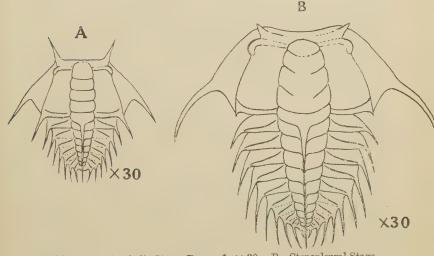
¹ Walcott, 1886, 1891, or 1910, pl. xxviii.

² Id. 1886, pl. xxv, fig. 2.

³ Id. 1908, pl. i, figs. 4–7 id. 1917 (A), pl. vii, figs. 3, 3a, & 3b.

are absent from Albertella. However, as if to make up for this failure, the last-named has the parial in a closely similar position to that which obtains in the Leptoplastus larva. In each of those forms the eyes are much more primitive than those of L. salteri, but each is specialized in other details:—Zacanthoides in its axial spine, and Albertella in its lateral tail-spines. They cannot be ancestral to Leptoplastus, but the close comparisons suggest common derivation from a seven-spine-headed form, probably of pre-Cambrian age, as there must be a common ancestor for these and for Olenelloides. The earliest stage may, therefore, be called a seven-spine-headed or Hept-aci-cephalic Stage of development. It is restored in text-figure A, below.

Leptoplastus salteri: outline restorations of early stages of its development, the free cheeks being represented as lifted into the same plane as the rest.



[A=Heptacicephalic Stage, Degree 1, \times 30. B=Ctenopleural Stage, Degree 5, \times 30.

For the succeeding Autogeneric Stage, see Pl. XVII, figs. 14 & 16; and for the Autospecific Stage, see Pl. XVIII, figs. 23 & 24.]

Olenelloides was regarded by Dr. B. N. Peach as adult, but Beecher suggested that it might be the larva of an unknown Mesonacid.\(^1\) Arguments are, however, given below (p. 287) for regarding it as essentially adult, while the adult character of the Zacanthoides and Albertella species has not been called in question. For this reason, and because a heptacicephalic form is suggested by early stages of other Olenidæ and Paradoxidæ, as well as Mesonacidæ, we may claim this stage in the ontogeny as representing a corresponding stage in the phylogeny.

¹ Beecher, 1897, p. 191.

The Ctenopleural Stage.

In the early degrees, namely 1 to 6, the postcephalic body is practically identical in character also with that of adults of some species of Ctenopyge, especially as represented by the less extreme forms, such as Ct. bisulcata Phillips and Ct. flagellifera (Angelin). Unfortunately this genus is very imperfectly known, owing to the fragmentary character of the specimens, the pygidium being well known only for Ct. pecten Salter. But, if we imagine the width of the pleural lobes of this pygidium reduced so as to fit the narrower pleura of the above-named species, we gain a conception of a complete form which we can call the Ctenopyge type. Westergard, moreover, figures a tail of Ct. flagellifera of just this type. A dominant character of the genus is the nature of its pleural terminations, alike of thorax and of pygidium. The same form of pleura also characterizes the closely related Sphærophthalmus.

Degrees 1-3, though well exhibiting the Ctenopyge type in the postcephalic body, are so strongly characterized by the three pairs of head-spines that they are here separated as the Heptacicephalic Stage; but, commencing with Degree 3 there is a continuous approach to the less extreme Ctenopyge species by (1) the reduction of the pro- and metacranidial spines (absent at least from the adult Ctenopyge), (2) the growing obliquity of the glabellar furrows, (3) the rounding of the cheek-margin, and (4) the widening of all the segments of the body. The continued presence of reduced pro- and metacranidial spines constitutes a distinction; while also the genus Ctenopyge itself is specialized in the forward position of all the anterior spines, not only the thoracic pleural spines, but also of the parial spines and of the loci of the programidial and metagramidial spines. With the great widening of the back of the head there has been here a rotation of the lateral margins towards the front, the very opposite of what has normally occurred in Opisthoparian Trilobites. The lately described Ct. neglecta Westergård 2 is the least specialized in this respect, and only differs from this stage of L. salteri in the greater width of the fixed cheek and the somewhat different position of the eyes. Agreement obtains with all the Ctenopyge species in spinosity, and also as regards the elongate cephalic axis reaching in front to the intramarginal furrow, and being well furnished with oblique glabellar furrows. If, however, we may use the term Ctenopyge in a somewhat loose sense for Olenidæ abruptæ with the thorax and pygidium of the Ctenopyge type, we should be justified in naming our second stage of development a Clenopyge stage, as was suggested in 1907. As, however, it is inadvisable to incorporate a generic name in the term, it may be called the Ctenopleural Stage, and is restored in text-figure B, p. 249. This stage extends from the larger individuals in Degree 3 to

Westergård, 1922, pl. x, fig. 22.
 Ibid. pl. x, figs. 10-18.

Degrees 6 & 7. And, since this stage is closely comparable with the most primitive adult *Ctenopyge*, a genus which belongs to the same subdivision of the Olenidae, we may confidently claim this stage in the ontogeny as also representing a stage of the phylogeny.

The Autogeneric Stage.

In Degrees 6 9 the Ctenopleural Stage passes gradually into a stage presenting the characters of the more primitive Leptoplastus species. This is effected (1) by the shortening of the pleural spines, and their assumption of an unguiculate shape; and (2) by the suppression of the pro- and metacranidial spines, and the reduction of the glabellar front. This stage covers Degrees 9, 10, & 11. It only differs from the earlier-described Leptoplastus species in being a larva, and so in having a smaller number of thoracic and a greater number of pygidial segments, the total number being about the same. Atrophy of the posterior segments has not yet taken place, and so the hinder end of the body is pointed, and the pygidial segments bear short pleural spines as in primitive Leptoplastus species. This very perfect primitive Leptoplastus stage in the ontogeny can be quite confidently accepted as evidence of a corresponding stage in the phylogeny also. These stages in both the ontogeny and the phylogeny may be most appropriately called the Autogeneric Stages. They are sufficiently figured in the photographs, Pl. XVII, figs. 14 & 16—especially if the somewhat telescoped hinder end of the latter is drawn out.

The Autospecific Stage.

In later development changes continue, and we reach in the Holaspid Period a stage unrepresented in the earlier-described Leptoplastus species. A tendency to atrophy affects the pygidial segments. The pygidium has changed in form from the triangular of primitive Leptoplastus, seen typically in Degree 9, to transversely semi-elliptical. The number of evident segments is reduced from 4 to 3; and the posterior composite segment being then further reduced, the tail becomes concave behind. At the same time, the pleural points from behind forwards come to be entirely lost. Dorsal spines, too, are here entirely lost; while those of the posterior segments of the thorax have been greatly developed. On the head the glabella becomes smooth.

Because this adult form seemed so distinct in its tail from the previously described *Leptoplastus* species, which were all well known as adults and had as a larva passed through a perfect *Leptoplastus* stage, the conclusion was inevitable that it represented a further stage in evolution. It was for this reason, that is, in order to recognize its phylogeny, that, when briefly describing

¹ See Persson, 1904, for *L. stenotus* Angelin, pl. ix, figs. 13-14 & *L. ovatus* Angelin, pl. ix, fig. 19; Westergard, 1922, for *L. raphidophorus* Angelin, pl. x, figs. 2-3 & pl. viii, figs. 16-17.

the development in 1907, I suggested for it the name of 'Lepto-

plastides'.

But Westergård's 1922 memoir on the *Olenus* Shales of Sweden has recently come to hand. He says of *L. stenotus* that the tail is broad, semicircular, and usually entire, but that it often develops a marginal spine in continuation of the foremost furrows, while rarely two or three pairs of rudimentary spines can be distinguished on the margin. Thus this species, which in other respects is the nearest to *L. salteri*, approaches it very nearly also in its tail. On the other hand, *L. salteri* is, in this respect, more highly evolved than all the other four *Leptoplastus* species figured and described by Westergård from the *Leptoplastus* Beds.

In view of the intermediate position occupied by *L. stenotus*, Mr. P. Lake was justified in leaving *L. salteri* within the genus *Leptoplastus*. But we can nevertheless recognize in the adult *L. salteri* a final stage, alike in the ontogeny and in the phylogeny,

which may be called the Autospecific Stage.2

The conclusion that L. salteri represents a stage of evolution higher than that of previously known Leptoplastus species is in agreement with what is known of its stratigraphical position. The previously known Leptoplastus species have not been recognized in Britain. In Scandinavia they come from the Eurycare and Leptoplastus Beds, which overlie the Parabolina-spinulosa Beds, and underlie the Peltura Beds capped by the Acerocare Zone. This is followed by the Dictyonema Shale; and thus those Leptoplastus species there appear limited to horizons well below the Dictyonema Zone. On the other hand, L. salteri comes from a horizon, which, whatever its exact position, is certainly well above that zone. The fauna of which L. salteri is a member suggests that of the Ceratopyge Limestone of Norway and Sweden, and cannot be older than the underlying Ceratopyge Shale. Prof. W. G. Fearnsides cites it also from the upper part of his Nant Ddu or Bellerophon Beds, which overlie the Dictyonema Shale. L. salteri is thus well separated in age from the previously known Leptoplastus species, and its higher geological horizon might be expected to place it in a higher stage of evolution. Considering the difference in stratigraphical horizon, the difference in evolutional rank . is, however, small.

But L. salteri does not stand isolated at the top of the Leptoplastus species. We have seen how nearly it is approached by L. stenotus, though L. claudicans (Moberg) seems much the nearest of all the species figured. It is represented by cranidium, free cheek, thoracic segment, and pygidium, and it appears to differ only in that the pleural lobes of the body were somewhat broader throughout: while the margin of the pygidium is even more entire than in L. salteri of the same size. Unfortunately, its geological horizon

¹ Westergård, 1922, p. 146.

² For the terms autogeneric and autospecific I am indebted to Mr. E. S. Cobbold, F.G.S.

is at present uncertain, since it occurred in a loose block of shale at Andrarum. Moberg described it as Acerocare, and attributed it to the Acerocare Zone. I claimed it in 1917 as a 'Leptoplastides' and a close relation of L. salteri. Westergård, doubtless in ignorance of this, claims it as a Leptoplastus, and for that reason assigns it to the Leptoplastus Zone. Now, however, that the range of the genus is extended into the Ceratopyge Zone, this last ascription may well be doubted, especially in view of its close approach to Leptoplastus salteri.

We have distinguished in the development of L. salteri three successive larval stages besides the adult stage; their distribution over the degrees of development is indicated on the left of Table III, below.

TABLE III .- DISTRIBUTION OF THE ONTOGENETIC STAGES OF LEPTOPLASTUS SALTERI, AND OF THE DEDUCED PHYLOGENETIC STAGES.

	Degrees in Ontogeny.	Stages in Ontogeny and Phylogeny.	Suggested Geological Horizons in the Phylogeny.
Holaspid.	12.	IV. Autospecific.	Lower Ordovician.
Meraspid	11. 10. 9. 8. 7. 6. 5. 4. 3. 2. 1. 0.	III. Autogeneric. (transition), II. Ctenopleural.	Upper Cambrian. Lower Cambrian. Pre-Cambrian.
Protaspid	l (unknown)		

Characters and Distribution of the Phylogenitors.

The four stages in the phylogeny to which, as above claimed, the ontogenetic Stages correspond, must have followed one another in the same order in geological time. In the case of Stages I, III, and IV, this is supported by the stratigraphical succession. It is not so with Stage II. The known species of the Ctenopyge type do not precede the primitive Leptoplastus species in geological time. On the contrary, they immediately succeed the latter; and in some respects are more specialized than Leptoplastus. But in their dominant characteristic—the form of their thoracic pleure they are more primitive; and they may represent immigrations of that type previously persisting elsewhere.

As we go back through the ontogeny, we find, in the Autogeneric

and Ctenopleural Stages, a combination of phylogenetic and of larval characters: for instance, in the Autogenetic Stage the characters of primitive *Leptoplastus* species (phylogenetic characters) are combined with a reduced number of thoracic segments (a larval character). The question, therefore, arises whether the early heptacicephalic character is phylogenetic or larval. The presence of spines, it is true, is highly characteristic of free-swimming crustacean larvæ; but, in the case of these seven spines, I am strongly in favour of attributing to their presence a phylogenetic significance. The reasons for this conclusion are as follows:—

- (1) The occipital and each of the pairs of spines persist on the cephala of different families of Trilobites, and are in general best developed on those members which are in other respects most primitive:
 - (a) The occipital and its homologues—the median spines of the postcephalic segments, whether as spines or vestiges characterize almost all families of Trilobites;
 - (b) The parial persist as the genal spines in Opisthoparian Trilobites;
 - (c) The metacranidials persist as the genal spines in Proparian Trilobites (see p. 281);
 - (d) The procranidials, as shown below, persist as the genal spines in the Mesonacidæ (see pp. 293, 303-306);
 - (e) All three pairs of spines persist in Olenelloides, which, there is much reason to believe, is adult (see below, p. 287).
- (2) Only seldom do any other spines appear on the cephala of Trilobites, and, when they do appear, they are quite different in character.
- (3) The facial sutures have above been shown to be closely correlated with each of the three pairs of spines; and these sutures are among the most characteristic features of Trilobites. They are shown below to be primitive even in the Mesonacidæ (p. 305).

(4) These spines, in a curious way, serve to connect the Trilobites with the Annelids, to which group they can be traced, as is explained in a forthcoming paper.

The facts, indeed, leave me in no doubt of the direct phylo-

genetic significance of the heptacicephalic character.

The cranidial spines persist, however, in the development, into the Ctenopleural Stage and in a very reduced condition even into the Autogeneric Stage, although no instance of their presence is known in the adults of *Ctenopyge* and *Leptoplastus*. Hence one might infer that the persistence of the full number of these spines suited larval conditions better than adult.

We can recognize, then, as many stages in the phylogeny as there are stages in the known ontogeny. But the phylogenetic stages were necessarily different from the ontogenetic stages of which they were the prototypes: for the former were a succession of adults, or at least of sexually mature individuals, whereas the latter are larvæ necessarily transitional between the spherical unsegmented egg and an elongate many-segmented adult. And, according to the extent of separation of any larval stage from the

adult within the ontogeny, so will be the discrepancy between that larval form and the form in the phylogeny which it represents; and the more so as three different principles are involved in effecting it:—

(1) The increasing separation from the adult, and approximation

to the egg;

(2) The increasing antiquity of the phylogenetic stage represented in the larva, and consequently the diminishing extent of its representation in that larva; or, in other terms, the weaker 'memory' of the organization for its more distant prototype; and

(3) The increasing abbreviation of the recapitulation represented

by the ontogeny.

Hence, in contrast to the relative accuracy with which the Autogeneric Stage in the ontogeny reproduces the primitive forms of the genus, the Heptacicephalic Stage can only in a very imperfect way reflect the corresponding stage in the phylogeny. If we apply the foregoing principles to the present case, it will enable us to define more closely the phylogenetic stages that have led up to L. salteri.

Though there may have been an evolution of size within the represented phylogeny, there is no reason to suppose that the size of the heptacicephalic ancestor bore any relation to the size of the corresponding ontogenetic stage. Again, there is no reason to suppose that any of them had a less number of segments than the greatest number represented in L. salteri, namely, sixteen segments besides the head; for within the ontogeny we recognize between Degree 11 and the adult a reduction of the segments, and, if the like had obtained throughout the phylogeny, the earlier stages would have had many more. Thus we can argue that the distant ancestor, far from resembling the Protaspis, as claimed by Matthew, Beecher, and Raymond, approximated instead to the Annelid.

The persistence of the cranidial spines in the Ctenopleural Stage of development, and the consequent overlap of the first two stages may also find explanation on these principles. Among the majority of adult Trilobites only one pair of head-spines persists, though in certain genera, such as *Holmia*, *Callavia*, and *Zacanthoides*, two pairs are found in the adult. This fact, and the absence of the cranidial spines from the adult *Ctenopyge* and *Sphæropthalmus*, would suggest that the cranidial spines may not improbably have been absent from the ancestor which the Ctenopleural Stage recalls. We may here have an illustration of the effects of Principle 2.

Again, as regards the eye, this organ in *L. salteri* is of a highly evolved type, and suffers little apparent change throughout development, having already in Degree 1 a concentrated form. On the other hand, the primitive *Albertella* and *Zacanthoides*, and practically all the Mesonacidæ, with which alone the Heptacicephalic Stage bears close comparison, are furnished with a very different and more primitive type of eye. It is reasonable, therefore, to suppose

that the corresponding ancestor was likewise furnished with this primitive type. The presence of the more highly evolved organ in the heptacic developmental stage of *L. salteri* may be attributed to tachygenesis—to the inheritance successively earlier in the ontogeny of this more highly evolved and later acquired type of eye, so as to function in the active life of earlier and still earlier larvæ.

With respect also to the axial lobe of the head, we must attribute to the heptacicephalic ancestor a more primitive condition than is indicated by the corresponding ontogenetic stage. For, if the above claims are true, this ancestor is more primitive than the most primitive Cambrian forms, which, like Albertella (see above, p. 248), Bathyuriscus, Elliptocephala, Arthricocephalus, Paradoxides, as well as certain Asaphidæ, Encrinuridæ, and Phacopidæ, have the cephalic axis clearly divided into six segments. The loss of the anterior segmental furrow here postulated, from even the Heptacicephalic Stage of the ontogeny might be attributed to the loss, or reduction, or change in the musculature of the anterior pair of limbs in the course of evolution, owing to their position under cover of the hypostome; and the inheritance of this loss constantly earlier in the ontogeny, until finally the furrow disappeared altogether from the known development.

In other respects, however, I accept the development as a true index of the phylogenetic trends. The extreme regularity of the cephalic segmentation in the earliest degrees, comparable at this stage with that of the thorax and pygidium, suggests the ideal primitive Arthropod; and, indeed, points beyond it to the Annelid. The great axial length of the segments of this earliest stage (the very opposite of that which one might expect embryonic conditions to effect), the short pleura, and the long and slender pleural spines furnish further details of this primitive form (see below, p. 310).

These considerations still leave us four well-characterized phylogenetic stages.

Leptoplastus salteri itself comes from a horizon which recent

workers would place in the Lower Ordovician.

The Autogeneric phylogenitor, in view of the stratigraphical horizon of the known species of the genus, may with confidence

be relegated to the Upper Cambrian.

The Ctenopleural phylogenitor, in view of the relative specialization of the known species of *Ctenopyge*, which hail from the Upper Cambrian, and the very primitive character of the thorax and pygidium in the Ctenopleural stage of *Leptoplastus salteri*, cannot well be placed later than Middle Cambrian, and may well be Lower Cambrian.

The Heptacicephalic phylogenitor could not well have persisted later than the Lower Cambrian to which Olenelloides belongs, and

¹ Walcott, 1917 (A), pl. v, fig. 6, and 1908, pl. i, fig. 1.

Id 1891, pl. lxxxviii, figs. 1 b & 1 c.
 Bergeron, 1899, pp. 514-17 & fig. 9.

in view of the specialization of this form and the relative specialization of Lower Cambrian Trilobites in general, must be relegated to the pre-Cambrian Era, and must have long antedated Cambrian time.

This is supported by the characters of Protolenus. This genus, the oldest-known member of the Olenidæ, which marks an upper zone of the Lower Cambrian, had already advanced a very long way from the Heptacicephalic ancestor indicated by the earliestknown stage of L. salteri. It had already lost both pairs of cranidial spines, and the parial spines had revolved to the rear; the evanescent anterior glabellar furrow had already disappeared, making the glabella (together with the occipital ring) appear to consist of five segments, although the anterior glabellar lobe had not yet been reduced, being still twice as long as the rest; while, finally, the genus had evolved a wide brim in front of the glabella. If it be accepted that Protolenus was derived from the same Heptacicephalic ancestor, the extent of its divergence from the same would relegate this ancestor to very far back in pre-Cambrian time. These suggestions regarding the geological distribution of the phylogenitors are expressed above in Table III, p. 253.

When we allow for all reservations, this trilobite in its development still to a very large extent recapitulates its phylogeny. It forms probably one of the best illustrations of the Biogenetic Law, furnishing the strongest support for the Recapitulation Theory.

The Development of other Trilobites.

VI. THE ONTOGENIES OF OTHER OLENIDÆ, AND OF PTYCHOPARIDÆ AND CONOCORYPHIDÆ.

The greater number of the developmental changes of *L. salteri* are common to members of several families of Trilobites. But some, at the time when they were first described in 1907, had never before been recorded of any trilobite; while the development, as a whole, differs greatly from that of all other trilobites equally

completely known.

Of 'Opisthoparia', the forms the known development of which is most complete are Suo hirsuta and Triarthrus becki. Beecher, and Raymond place both of them in the Olenidæ, in which also L. salteri would fall, and Walcott by implication would do the same. Gürich removes Triarthrus from the Olenidæ to the Ellipsocephalidæ. Chapman and Swinnerton, on the other hand, separate both genera from the Olenidæ, the former placing them in separate families, the latter assigning both to the Ptychoparidæ.

¹ Matthew, 1893, p. 100. ² Beecher, 1897, p. 192.

Raymond, 1913, p. 715.
 Walcott, 1918, pp. 135 & 144.
 Gürich, 1907, p. 133.
 Chapman, 1889, pp. 117, 118, & 120.

⁷ Swinnerton, 1915, p. 542.

The Ontogenies of Ptychoparidæ.

Comparison with Sao.—The various stages of development of Sao are beautifully preserved, and the earlier stages are much more completely represented than is the case with L. salteri.¹

The single Olenid protaspis referred above to a larger species than *L. salteri* compares fairly closely with the earliest stages of *Sao*, the only important difference being that the axis shows no trace of the widening in front, while also there is very little

representing the pygidium.

In later stages Sao and Leptoplastus agree: first, in the relative widening of the head, and of the segments of the body, and especially of the glabella accompanied by shortening of its anterior lobe; secondly, in the change of the tail from spinose to entire. But in several characters L. salteri presents a wide divergence. The narrowness of the glabellar front in early stages markedly contrasts with the very broad front of the larval Sao, continued until nine or ten segments have been liberated into the thorax; and the change in direction of the glabellar furrows with development is quite different. Further, the presence in early stages of the procranidial and metacranidial spines and their gradual loss, spread through the Meraspid Period, has no equivalent in Barrande's description.

The study, however, of these early stages of Trilobites is very difficult; and, as so much depends on the state and nature of preservation, it may well be that it is not possible yet to institute just comparisons between them. They have to be studied with the microscope, which only gives a vertical view; and, as practically all are markedly convex—indeed, approximately hemispherical,—we do not see the peripheral parts which are embedded in, and so truncated by, the rock-matrix. It seems to me not improbable, therefore, that in development Sao may be much closer to Leptoplastus salteri than would appear from Barrande's

figures and description.

Barrande did not recognize more than one pair of cheek-spines, namely, the genal spines of the adult, and so he may have confused metacranidial and parial spines. For, in his description, he states concerning his 'degree 3' (that is, just before the free thoracic segments appear):—'some have preserved the rim which surrounds the cheeks, and is prolonged at the genal angles into a point parallel to the axis.' The same description applied to the '4th degree' with two thoracic segments, but 'individuals of the 5th degree' with three thoracic segments 'show us the genal points sometimes applied along the body, sometimes fairly strongly divergent.' One may remark that, if both parial and metacranidial spines were present in early stages, and if changes occur similar to those that are found to arise in the development of Paradoxide and Mesonacidæ, the metacranidial spines occupying at first the posterolateral angles, as in early stages of L. salteri,

¹ Barrande, 1852, pp. 386-403 & pl. vii.

would be replaced later by the parial spines previously directed more outwards. Before replacement both pairs of spines would exist simultaneously, but, being at different levels, only one pair would usually be exposed.

The early development of Ptychoparia linnarssoni Brögger, 1 Solenopleura robii (Hartt). Liostracus ouangondianus (Hartt),3 and Agraulos hallianus Matthew, all described and figured by Matthew in 1887 and 1889, is closely similar to that of Sao, and thus would support their attribution to the same family.⁵ In each of the species, the form in early stages is very convex, and the margin does not appear.

The Ontogenies of Conocoryphidæ.

Matthew, besides, in 1884, had described the development of three species of Conocoryphidæ.6 Of these Ctenocephalus (Harttella) matthewi (Hartt) is in this connexion of most interest. In the earliest stages (cephala 1 mm. and 1.33 mm. long) the glabella closely resembles that of Ptychoparia above mentioned, but each stage is furnished with 'genal spines' which curve inwards round the missing thorax. The inner edge of these spines is continued in the concave posterior border of the cheeks. The later stages met with do not bear genal spines, except for one individual with a head-length of 9 mm. In this, an adult, the genal spine is separated from the posterior border by a marked indentation. In the light of the development of L. salteri, and, as we shall see, of Paradoxides, we can interpret this development of Ctenocephalus in a new way. The suggestion is that the spine of the earliest stages is always there because it is the metacranidial spine and so part of the cranidium, and it is a continuation of the posterior border because it is the pleural spine of the segment which makes that border—the occipital segment. This spine is reduced and lost in later development, and is replaced in position and function by the parial spine, which, being on the free cheek, is seldom found in position. Exactly the same development, so far as these spines are concerned, obtains in Conocoryphe (Bailiella) elegans (Hartt) described in the same place, 8 while again in C. (Bailiella) baileyi 9 the 'genal' spines are only met with in the youngest stage. Not improbably we may have in both the Ptychoparids and the Conocorvphids a succession in the spines that function as genal spines (see pp. 276, 307).

¹ Matthew, 1887 A, pp. 149-52 & pl. ii.

² *Ibid.* pp. 155–57 & pl. ii.

³ *Ibid.* pp. 140–42 & pl. i. ⁴ *Ibid.* pp. 132–33 & pl. i.

⁵ Raymond, however, separates Solenopleura from the others as the type of the family Solenopleuridæ, leaving the rest in the Olenidæ; see Raymond, 1913, pp. 715-16.

⁶ Matthew, 1884, pp. 102-24 & pl. i.

 ⁷ Ibid. pp. 107-11.
 9 Ibid. pp. 112-14 & pl. i. ⁸ Ibid. pp. 116-18 & pl. i.

The Ontogeny of Triarthrus becki.

A comparison may be made also with Triarthrus becki Green,¹ already noticed on pp. 225, 227. The two stages of the protaspis are oval in outline, markedly convex, and do not show any marginal rim, except in front. This is peculiar, seeing that. in all Walcott's degrees except the adult, the marginal rim is invisible here in front as well as round the sides of the cephalon. lack of evidence of a marginal rim may be due to its absence until a late stage in this species, but is perhaps more probably due to its convexity, and its consequently incomplete exposure in the splitting of the shale. If so, Triarthrus becki perhaps would not show head-spines, were they present in early stages. The axis of the protaspis is cylindrical, narrowing in the pygidium, rounded in front, divided by simple annular constrictions into segments. These over the cephalon are subequal, except for the anterior segment which is nearly twice as long as the rest, while from it prominent eye-lines run out to be lost at the edge. Thus, so much as is seen of the cephalon of this protaspis of Triarthrus might almost be the protaspis of Leptoplastus. Whether in this early stage it possesses any of the three pairs of head-spines is not revealed, but against their presence is the fact that the pygidium shows no marginal points.

In the later development described by Walcott the changes of character are very much less than in *L. salteri*. This is to no small extent due to the absence of spines, and to the relative constancy of the glabella. The adult is without spines on the margin of the head, thorax, and pygidium; and no such are recorded for any earlier stage. This is doubtless a secondary specialization, and it may well be that in the long range of the genus from Upper Cambrian to Upper Ordovician time the presence of these spines on the margin has been pushed back out of the known development. Only along the dorsal mid-line do short spines persist, these being found throughout development on the occipital segment, on each thoracic segment, and on the anterior segment of the pygidium—a distribution which suggests connexion with the articulations.² They may have been a pro-

tection to the softer cuticle exposed at the joints.

In the glabella and the frontal brim Triarthrus becki is at least as primitive as L. salteri, if not indeed more so, and the development (though similar) does not extend so far. But the effect of earlier inheritance is seen again here: as already noted above, the three glabellar furrows in the protaspis are, like the neck-furrow, simple annular constrictions as in Degrees 1 to 3 of L. salteri; but here already in Degree 1 with one thoracic segment the glabellar furrows are discontinuous, penetrating only for a third of the distance across the glabella, and represent simply the two posterior constrictions. Moreover, judging from the figures, they are already

² Raymond, 1920, pls. i & ii.

¹ Walcott, 1879, pp. 23-33 & pl. ii; Beecher, 1895, p. 172 & pl. viii, figs. 12-13.

somewhat oblique, and so compare with *L. salteri* at a much later stage: say, Degree 9 or 10. Thus the simplest expression of the segmentation has been almost pushed out of the development by tachygenesis, surviving only in the protaspis. Throughout development the glabella widens, but does not withdraw appreciably from the frontal brim; while it retains its furrows up to the largest sizes, in which not only do the anterior furrows reappear, but a fourth pair also appears, variously interpreted by authors as denoting a 6th segment of the cephalic axis or merely an interpolated

muscle-impression.¹
Thus, to sum up

Thus, to sum up the comparison: Triarthrus becki and Leptoplastus salteri agree in their development in features which were previously known to characterize many Trilobites, but some points which especially characterize the development of L. salteri (the loss of spines on head and tail, and the change of form of the terminations of the thoracic pleuræ) have apparently no counterpart in T. becki. Loss of spines characterizes, however, the later members of more than one branch of Trilobites, as, for example, Acerocare among the Olenidæ abruptæ to which Leptoplastus belongs; consequently, their absence in Triarthrus seems quite reasonable, on the principle of earlier inheritance just cited as affecting other characters. But, besides the general agreements, these species coincide in other particulars which indicate a nearer relationship.

Indications of relationships.—As writers are not in accord as to the relations between these forms so far compared, we may note the bearing which their individual ontogenies have upon the question. We may confidently take development, when complete, as a valuable test of affinity. And if now we compare the earliest stages of Sao, Ptychoparia, Triarthrus, and Leptoplastus, we note that those of Sao and Ptychoparia separate themselves from those of Triarthrus and Leptoplastus. In the first pair, as also in the related Liostracus and Solenopleura, the glabella is inverted-conical in form with indistinct segmentation; while in the second pair it is cylindrical, with segmentation marked by clear annular constrictions. Thus these ontogenies may be taken to indicate an early divergence between the rootstocks of the Ptvchoparidæ and of the Olenidæ, and so strongly support the separation of these families; and they show, besides, that Triarthrus belongs to the Olenidæ. Furthermore, they indicate a close relationship between the Conocoryphidæ and the Ptychoparidæ,2 the former being most reasonably interpreted as secondarily 'blind' scions of the Ptychoparidæ, and so bearing a like relation to the normal Ptychoparidæ as the 'blind' species of Illanus bear to the normal species. If such an interpretation of this relationship be accepted, it would be well to revive the familyname Conocephalidæ, and to place under it as subfamilies the Ptychoparidæ and the Conocoryphidæ; for, under Conocephalites,

¹ See Raymond, 1920, pp. 69 & 70.

² Matthew, 1884, p. 102; id. 1887, B, p. 358.

Barrande included members of both these families. This conclusion, however, is diametrically opposed to that advanced by Beecher and supported by Dr. F. R. C. Reed, namely, that the Conocoryphidæ (in common with the majority of 'blind' genera of Trilobites) are primitively blind, deriving from a primitive Trilobite stock, before dorsal compound eyes had been evolved.

While the development of *Leptoplastus salteri* is not closely comparable with any fully described ontogenies, most features can be closely matched among related forms belonging to the Olenidæ, and it bears comparison also with the ontogenies of Paradoxidæ and Mesonacidæ.

The Ontogenies of other Olenidæ.

The evidently close relationship between the genera Ctenopyge, Bæckia, Sphærophthalmus, Eurycare, Leptoplastus, Acerocare, and Peltura, all belonging to Persson's divisions Abruptæ and Inermes of Olenus sensu lato, would suggest that they may all be confidently expected to have a like early development, especially as their stratigraphical range is so restricted. Again, a similar development modified in details might be expected for the other genera: namely, Olenus sensu stricto, Parabolina, and Parabolinella.

Angelin, under 'Anopocare pusillum,' figures two minute cranidia, the larger of which (3 mm. long) he regarded as adult.¹ Linnarsson identified them as Sphærophthalmus alatus Bœck.² The procranidial spines are absent, as is the case in L. salteri in this size; but the metacranidial are present, suggesting that Sphærophthalmus is more primitive in this respect than Lepto-

plastus.

Moberg & Möller, in their paper 'Om Acerocarezonen' (1898). figure and describe larval cephala of a number of the Olenids from that zone, most of them from 'orsten' [stinkstone] or from limestone. They remark on the greater convexity of these early stages than of the adult, beyond what must be allowed for the greater flattening by distortion of the larger individuals. The larvæ are attributed to the genera Acerocare and Parabolina. Acerocare lies at the summit of a line of evolution from the Abruptæ of Persson, being characterized by the absence of spines on head. thorax, and tail, though retaining them along the dorsal mid-line. But, notwithstanding the spineless character of the adult, the larvæ of Acerocare ecorne, A. micropygum, A. granulatum are all described as possessing 'sharp spines extending the outer back angle of the fixed cheek', and thus corresponding to the metacranidial spines of L. salteri. The genus Parabolina, on the other hand, being in regard to spines so much more primitive, it is less surprising that the larval stages of P. acanthura and P. heres should be furnished as they are with metacranidial spines.

Angelin, 1854, p. 50 & pl. xxvii, figs, 1, 2, not 1a.
 Linnarsson, 1880, pp. 136 & 140.

These cephala correspond in size with those of *L. salteri* in Degrees 4 to 6, and in the axial lobe they exhibit the five annular segments characterizing the earlier degrees of that form. This is the case also with the larva of *Leptoplastus claudicans*, figured by Moberg (1898) in a supplement, and of *L. ovatus* figured by Persson.

Two species of *Bæckia*, a genus of Abruptæ nearly related to *Sphærophthalmus*, also exhibit metacranidial spines in larvæ:

namely, B. mobergi Wiman and B. jarensis Störmer.1

Young forms of an *Olenus* sensu stricto are figured by Mr. P. Lake.² His fig. 4 with apparently six segments in the thorax is, in the axis of its head, almost identical with *L. salteri* in Degrees 1 to 3. The eye-line and palpebral lobe are also comparable. The cheeks, however, are represented as conforming to the adult *Olenus* type; but no reliance can be placed on this, in view of the

very poor preservation of the specimen.3

Several larval stages of Norwegian Olenids are figured and described by Prof. O. Holtedahl (1910). They are particularly interesting, in that they show their natural form, and are excessively convex, confirming the indications of convexity in the larval stages of *L. salteri* and the Swedish forms noted above. He also figures two larval stages of *Leptoplastus ovatus* (Holtedahl, 1910, pl. i, figs. 8 & 9). The smaller is excessively minute, and compares closely with the earliest stage of *L. salteri* in individuals where the spines are invisible; while the larger (perhaps 1 mm. long) is a cranidium, very close to *L. salteri* at the same size.

Dr. Holtedahl figures also larval head-shields of Peltura præcursor Westergård (pl. ii, figs. 9 & 10), Olenus truncatus (pl. ii, fig. 11), Ctenopyge flagellifera, and Leptoplastus bröggeri. With the exception of those of Peltura præcursor, which differs by its narrowness, all these larvæ are so close one to the other and to L. salteri larvæ that it would appear impossible to distinguish them, and they can only be named by their association with identifiable adults. Holtedahl remarks that even the broad Eurycare latum in early stages closely approaches the typical form. Their similarity indicates a close relationship between the genera represented, and so their descent from a common ancestor not far distant in geological time.

The larval cephalon of Ctenopyge flagellifera is especially interesting. It is excessively minute, apparently 0.5 mm. wide or 0.33 mm. long, and so smaller than the smallest available specimen of L. salteri. The axial furrows are very deep, and its axis and cheeks are strongly arched, both from front to back and from side to side. Its axis is excessively long and narrow in proportion, projecting beyond the cheeks in front as well as behind, and deeply divided into tive long segments. It has indeed precisely

³ Ibid. p. 59.

Störmer, 1922, pl. i, fig. 8.
 Lake, 1908, pl. vi, figs. 4 & 5.

the form of a still earlier stage required by the known development of *Leptoplastus salteri*, and one can confidently accept it as approximating to an as yet unrecognized stage of development of that trilobite.

Unfortunately, in none of the beautiful examples figured by Holtedahl were any traces of cranidial or parial spines detected. But, while this is disappointing in view of one's confidence in their presence, it is only what might be expected. They are presumably preserved in limestone, and retain the natural convexity: thus the spines will penetrate the rock in directions approximately continuing the merospherical form of the test, and so would not be detected. Three circumstances have conspired to reveal them in L. salteri: first, the hemispherical or semiovoid trilobite tests, lying upside down, were filled with fine clay, and then later were opened out into the planes of lamination owing to the settlement of the sediment. Secondly, in the material revealing the spines the shell has been entirely removed by weathering, thus causing the splitting of the shale to follow them. Thirdly, the individuals occur in numbers so vast that it has been possible to accumulate

evidence to settle each doubtful point.

In the examples figured by Angelin, Moberg & Möller, and Störmer, although the metacranidial spines can with certainty be identified, neither the occipital nor the parial have been recorded. Even in the spineless Acerocare the metacranidials persist in larval stages, although they are lost in all adult Olenids; while, on the other hand, the occipital and the parial spines are not seen, though they persist to the adult in the great majority of Olenid genera. We can, therefore, confidently furnish the free cheeks of these larvæ with parial spines, and the neck-segment with an occipital spine. And, considering the close relationship that obtains between these Olenids, it is reasonable to assume that the procravidials also may have been present in the early stages. This assumption gains support from the fact that, although the occipital spines which characterize the adults are borne on the cranidium and, being primitive, were almost certainly present in early stages, they also have not been observed. Moreover, in Acerocare ecorne it seems not unlikely that the programidial spines slightly migrated may persist to the adult, being represented by the 'small, usually weak, but sometimes strongly-marked rounded tubercles' just within the anterolateral angles of the cranidium. Very strangely, in another Acerocare cranidium (A. tullbergi Moberg & Möller) the metacranidial spines persist as short spines to the adult.1

If the procranidial spines were absent from the ontogenies of other Abruptæ, their presence in *L. salteri* would have to be regarded as a reversion, which seems much less probable; but

With this are associated under the same name a hypostome, a large thorax, and a pygidium. All these, however, are quite different from such as characterize Acerocare, and must belong, I think, to another subgenus, perhaps Parabolinella, Moberg & Möller, 1898, pl. xiv, figs. 6-9.

even should they prove to be absent from the ontogeny of other Olenids, their proper loci are well marked, and point to their presence in the phylogeny.

Summary.

The conclusions that follow from this comparison with the ontogenies of other Olenidæ, of Ptychoparidæ, and of Conocory-

phidæ, may be briefly summarized.

The other Olenidæ, both the Abruptæ and the Continuæ, agree with L. salteri:—(1) in the form of the glabella in early stages, and its subsequent changes, including (a) reduction of the front, and especially of the anterior lobe, which from being the longest comes to be the shortest, and (b) the concomitant change in the form towards a somewhat conical shape; (2) in the presence of metacranidial spines in early stages, and their subsequent loss: besides (3) in reduction of the relative length of pleural spines; and (4) in the broadening of the segments throughout the body, which characterizes Trilobites in general. With the Olenids the Ptychoparids also largely agree, except in the early form and subsequent changes in the glabella. But, although in both families the loci of the procranidial spines are marked by an angle in the suture, these spines have only been recognized in L. salteri. It is concluded, however, that they existed in the phylogeny of both families, and that at least in the Abruptæ-Inermes they will be found in the ontogenies.

Triarthrus becki by its early development shows itself to be an Olenid, and its apparently spineless character in the earliest stages may be attributed to tachygenesis. Here it may be remarked that Triarthrus is one of the Abruptæ, and, when furnished with

genal spines, has these turned outwards from the margin.

The Ptychoparid Sao seems to exhibit metacranidial spines in early stages. This is more certainly the case in several Conocoryphids, which, having also an early development practically identical with that of Ptychoparids, might well be grouped with them in the same super-family, of which they would form secondarily 'blind' members. Here it may be remarked that in both these families, as also in the related Calymenidæ, a rostral plate or epistome persists, a condition which never obtains in the Olenidæ.

These two—Olenidæ and 'Conocephalidæ'—have thus much in common in their development, and, seeing that a phylogenetic significance is above attributed to the development of Leptoplustus, the claim is also made that the Olenids, Ptychoparids, and Conocoryphids all descend from a holospinous form: that is, one with a seven-spined-head and a spiny post-cephalic body, all the segments being furnished with pleural and axial spines.

The common ancestry of the Olenidæ and 'Conocephalidæ' must not only antedate the divergence between the Ptychoparidæ and the Conocoryphidæ and the divergences within the Olenidæ, but must also antedate the presumably very ancient divergences in

glabellar form which are indicated by the different shapes of glabellae and the lengths of the glabellar segments in the earliest ontogenetic stages of these two great families. Hence their common ancestry must be very ancient, and was presumably limited to the Heptacicephalic Stage. The closer resemblances between the forms in the two families must, therefore, be attributed to parallel evolution and to convergence.

VII. THE ONTOGENIES OF PARADOXIDÆ.

The earliest stage of *L. salteri*, where the metacranidial spines are associated with a facial suture, immediately suggests comparison with Barrande's genus 'Hydrocephalus', which in the light of this ontogeny immediately falls into place as a stage of development of Paradoxides, as was claimed by Beecher in 1893. Thus in 1909, in a paper read to the Birmingham Natural History and Philosophical Society, I claimed that Paradoxides had passed through a similar development, 'Hydrocephalus' carens Barrande developing through Paradoxides inflatus Corda into P. spinosus Beeck; and H. saturnoides Barrande through P.

orphanus Barrande into P. bohemicus Beek.

The identification of 'Hydrocephalus' with Paradoxides was, however, as early as 1877 partly anticipated by Linnarsson, when he described a larval stage of Paradoxides, perhaps of P. ölandicus Sjögren, under the name P. aculeatus. This larva had long palpebral lobes, and metacranidial spines immediately behind them, suggesting comparison with Hydrocephalus. He was ready 'to regard Hydrocephalus as a development stage of Paradoxides', and he regarded its spine not 'as a true genal spine..., but analogous with the spine which is found in "Paradoxides" (now Holmia) kjerulfi Linnarsson about mid-way between the genal spine and the dorsal furrows.' ³

Linnarsson thus properly evaluated its characters. Ford, however, who had described the development of *Elliptocephala* asaphoides (Emmons), came to a different conclusion 4; but it was Beecher who first definitely expressed the conviction that

Hydrocephalus was a larval stage of Paradoxides.

Material for the study of the development of *Paradoxides* has been furnished chiefly by Barrande and Matthew, and the subject has been discussed by the latter and by Raymond. Barrande figured the later developmental stages of *P. bohemicus* Bœck,⁵ and of *P. spinosus* Bœck,⁶ both short-eyed species, from individuals having cephalic lengths of 4 mm. and of 4.7 mm. respectively. Matthew traced the later development of the cranidia of *P. eteminicus* Matthew and of *P. acadicus* Matthew, both long-eyed species, from the St. John Group (New

¹ Barrande, 1852, pl. xlv.

Beecher, 1895, p. 176 & 1897, p. 190.
 Linnarsson, 1877, p. 360 (translated).
 Ford, 1881, p. 258.

⁵ Barrande, 1852, pl. x. ⁶ *Ibid.* pls. xi, xii, & xiii.

Brunswick), from cephalic lengths of 4.5 mm. and of 4.0 mm.

respectively.1

In the two series established by Barrande the changes are not great, except in regard to the pleural spines of the thorax. But in the early stages of both of Matthew's species there is in front of the comparatively short glabella a wide brim which is quite absent in the adult. The noteworthy features in the development, which is limited to the cranidium, he summarizes as follows:—

'(1) Widening of the extremities of the anterior marginal fold (rim) and absorption of the central part of the flat area (brim).

(2) Enlargement of glabella in all directions, and retreat of the fourth

furrow from the front of the glabella.

(3) Transverse lengthening and axial condensation of the occipital ring.

(4) Enlargement and strengthening of the posterior margin.

(5) Longitudinal contraction of the eye-lobe.' 2

Regarding changes 1 and 2, he thought that there was evidence for 'the transfer of narrow zones of the head-shield (brim) to the glabellar area' and 'of similar belts to the rim of the shield.' 8

He remarked also that the occipital spine 'present in the younger stages of all [his] species and varieties' is gradually reduced during change 3, being in some cases absent altogether in the later stages of growth. The rapidity of the changes during the earlier stages in contrast with the later stages is also especially noted—a character equally striking in L. salteri.

Raymond, combining these observations of Barrande, Matthew, and Beecher, claims the development of Paradoxides from Hydrocephalus: namely, that of P. rugulosus Corda from H. saturnoides Barrande. He also briefly summarizes the ontogeny of

Paradoxides in general in the following passage:—

'The youngest shell or protaspis is very similar to that of Olenellus. The glabella in Hydrocephalus is specialized, and unlike that of any other trilobite of which the young is known, in that it occupies a large part of the head, is very wide, and bears no transverse furrows. The first furrow to appear is a median longitudinal one, which is obliterated at an early stage. Glabellar furrows are introduced in young stages, and in later stages of development there seems to be no reduction of furrows.... The glabella occupies the whole length of the cranidium in the youngest stages known, becomes proportionately shorter during some of the early nepionic stages (pusillus stages), and becomes longer again in the neanic and early ephebic stages. The palpebral lobes are, in general, very much longer in young stages than in later ones, but many species are primitive in this regard, and retain the long eyes at maturity (P. rugulosus group). Most of the adult characteristics are assumed at an early age, so that specimens 6 to 10 mm. long are often almost identical in form with the adult; but certain minor features, such as the lateral extension of the second thoracic segment, persist well on into the ephebic stages.' (Op. cit. pp. 234-35.)

Studying the development of *Paradoxides* in the light of that of *L. salteri*, I reached conclusions which are different in detail,

¹ Matthew, 1882, pp. 93-107, pl. ix.

² *Ibid.* p. 106. ⁴ Raymond, 1914, p. 228.

as well as less simple than those of Raymond; and it is hoped that the following reading of the development will furnish facts and ideas of some value.

Barrande distinguishes two species of 'Hydrocephalus': namely, 'H. carens' and 'H. saturnoides', the former ranging from 2.0 to 3.5 mm. in length, and the latter from 1.0 to 1.3 mm. It is, however, probable that more than two species of Paradoxides are represented by these larve. H. carens, for example, includes a wide and narrow form; and distinct species of Paradoxides might be expected to differ very little in such early stages (see ante, pp. 259, 263).

In both species the glabella, in marked contrast with the conditions obtaining in other trilobite larvæ, is enormously swollen. I am indebted to Dr. Perner for two examples of Hydrocephalus saturnoides and one of H. carens. The latter is very close to Barrande's fig. 4, but those of H. saturnoides have the glabella less swollen than his figures, being just double as wide as the fixed cheek. Raymond also figures a Paradoxides larva, but in this

only the anterior lobe of the glabella is much expanded.2

In the youngest forms of both species of Hydrocephalus there is no segmentation of the glabella, but they exhibit a longitudinal furrow regarded by Barrande as a characteristic of the 'genus' and a distinction from Paradoxides. Raymond also accepts it as a natural feature. This longitudinal furrow, however, varies much in extent in Hydrocephalus, and is not even always present³; it is, I believe, purely secondary, being a natural result of compression in a flexible hemispherical or semi-ovoid test, its longitudinal character being further determined by the strengthening of the sides by the axial furrows and the palpebral lobes. The effect may be compared with the frequent result of compression on a hollow indiarubber ball.

The occipital furrow is in each case strongly marked, but even in the largest figured of H. carens (3.5 mm. long) only the posterior glabellar furrow has appeared, although in 'H. saturnoides' of less than half this (1.3 mm. long) three transverse glabellar furrows are developed; while in Raymond's larva of perhaps 1 mm. length the glabellar furrows are deeply incised, and the swollen anterior lobe is twice as long as the others behind.

In both Barrande's species of Hydrocephalus the head-shield as figured shows only the fixed cheeks, which bear at the back long metaeranidial spines. The sides are indented at the eye-line, in front of which the anterior branches of the facial suture run straight forward and outward to cut the margin at right angles; while behind, the palpebral lobes extend towards the pleuræ of the occipital segment marked by its pleural furrow. Thus Hydrocephalus, like Leptoplastus salteri, suggests by its form that

² Raymond, 1914, pl. fig. 8.

¹ Barrande, 1852, pp. 377 & 380, pl. xlix.

³ Barrande, 1852, H. carens, pl. xlix, figs. 1, 6, & 9.

the metacranidial spines are the pleural spines of the occipital

segment (see below, p. 288).

The palpebral lobe loses its relief some distance in front of this, and would appear to be quite distinct.\(^1\) The lateral contour indicates that free cheeks must be supplied to complete the head-shield, and Barrande restored these, representing them as having a simply rounded outline continuing the anterior border backwards, and ending on a line with the posterior border of the cranidium.

In the particularly perfect specimen of H. saturnoides received by me from Dr. Perner the free cheek is clearly present on the left side, shifted inwards somewhat in front, so as slightly to overlie the palpebral lobe. Its anterolateral contour is continued back into a parial spine. A trace of the right cheek is also present. Appreciating with Linnarsson that the spines figured by Barrande are the intergenal or metacranidial, we can with reason restore the head-shield by adding a free cheek extending from the anterior limit of the suture to the metacranidial spine, and bearing about or behind its mid length the representative of the genal spine of the adult Paradoxides.

Considering, however, the great development and the position of the metaeranidial spines in the earliest stage of Hydrocephalus, it is probable that these were then dominant, and it is possible that the parial spine on the free cheek was suppressed in that stage, as appears to occur also in some Mesonacidæ (pp. 293, 295, 297). If such were the case, Barrande's restoration would be correct for the earliest stage, and it would constitute a pro-

parial stage in the development of Paradoxides.

Procranidial spines, on the other hand, have not been detected even in the youngest 'Hydrocephalus', notwithstanding the excellent preservation and exposure of the fossils; but the sharp angulation of the outline of the cranidium where the anterior branch of the dorsal suture meets the anteromarginal suture must have the same significance as in later stages of L. salteri, and mark the loci of these spines, apparently lost altogether from the known development. It may be recalled that in L. salteri the procranidial are the first to disappear from the margin. Thus the later degrees of Hydrocephalus can be compared with L. salteri in Degrees 7 to 10 before the metacranidial spines disappear.

Behind the head-shield with its metacranidial spines, the segments (according to Barrande) are all free, except in the largest *H. carens*, where as many as two may be united into a pygidium. But Barrande's figures and descriptions and the specimens that I have examined admit of a different interpretation. The postcephalic segments in early stages appear to have no pleural spines, such as we should certainly expect to see in free segments of larvæ of such primitive trilobites; and we cannot attribute their absence to poor preservation. Moreover, the lines between the segments are faint,

¹ See Ford, 1877, on Elliptocephala larvæ.

suggesting their union; while in the adult up to five segments are represented in the pygidium, and their union is very complete. To me it appears that 'Hydrocephalus' has in early stages a transitory pygidium, the rudimentary segments of which have the spines of their pleuræ suppressed; but, with increase in number and size of these segments, they are freed one by one into the thorax, and develop pleural spines. These spines on the first two segments attain, according to Barrande, a special development, and the first a greater development than the second, reaching in H. carens the back of the body, and in H. saturnoides much farther. These pleural spines in the largest of the last-named mimic exactly the metacranidial spines in development and direction, as is the case in larvæ of Leptoplastus salteri and of Elliptocephala; but in H. carens they are directed more distinctly outwards, and the metacranidials overlie them, just as in the adult Holmia kjerulfi (Linnarsson), a condition which is probably related to the backward migration of the parial spines, combined with rapid widening of the lateral lobes of the thorax.

Comparing the young larvæ of *L. salteri* with those of *Paradoxides*, we note that both are chiefly head; both have a glabella reaching the anterior marginal rim, while *H. saturnoides* and Raymond's larva have the glabella simply segmented as in *L. salteri*; both have fairly straight suture-lines cutting the posterior margin immediately outside metacranidial spines; and in both the thoracic pleuræ have long spines repeating the form of these metacranidials.

But their differences are considerable. Hydrocephalus is unique in the swelling of the glabella throughout its length: this feature, from comparison with other forms, must be accounted a specialization. Again, the long palpebral lobe extending back nearly to the metacranidial spine is in marked contrast with the short lobe in an anterior position in L. salteri. But, in this respect, the condition in Hydrocephalus is undoubtedly the more primitive, as proved by the further development of Paradoxides 2 and by the geological succession of species.³

In other features, besides the glabellar swelling, Hydrocephalus is the more advanced: namely, in the absence or earlier loss of procranidial spines, and in the reduction of dorsal spines (both of the occipital segment and those behind it) to vestiges. How much significance is to be attached to the absence of pleural spines on the segments of the pygidium of Hydrocephalus is perhaps doubtful; but, in the light of the ontogeny of L. salteri, and for other reasons, this also must be accounted a specialization. 'Hydrocephalus', indeed, proclaims itself a specialized larva.

We cannot recognize a typical Heptacicephalic Stage in the ontogeny of *Paradoxides*, owing to the absence of procranidial

Walcott, 1891, pl. lxxxviii, figs. 1b, 1c, & 1d, or 1910, pl. xxiv, figs. 3 & 4.
 Matthew, 1882, pp. 97 & 106.
 Id. 1884, B, p. 101.

spines. The potential position of these is, however, clear, and hence the characters of *Hydrocephalus* point to a Heptacicephalic ancestor of *Paradoxides* as for *Olenus* sensu lato.

Not only 'Hydrocephalus' but Barrande's species Paradoxides pusillus, and P. orphanus, as well as P. inflatus Corda, are based on immature individuals of Paradoxides, as Raymond points out. The latter traces a line of development from 'H. saturnoides' through 'P. orphanus' and 'P. pusillus' to P. rugulosus, and gives reasons for regarding them as the growth-stages of one species.

In the largest H. saturnoides with a head-length of 0.9 mm., with perhaps two free segments and the rest united in a transitory pygidium, the pleure might be described as truncated by their own backwardly directed spines. P. orphanus, with a head 3.3 mm. long, exhibits the same form of pleure2; and its cranidium is quite comparable with that of H. saturnoides, for its glabella is simply segmented, though the anterior or third pair of glabellar furrows are no longer continuous across the glabella, and a fourth pair is now seen in front of the palpebral lobe. The margin in front is narrow, and the palpebral lobes are long, exactly as in H. saturnoides. Raymond, moreover, bridges the gap between these by describing a P. orphanus in the Museum of Comparative Zoology at Harvard College with a head 1.5 mm. long, as having a narrow brim as in Barrande's figure, and showing three furrows crossing the glabella.3 Hence we may well agree with Raymond that a Hydrocephalus of saturnoides type developed into P. orphanus.

But with P. orphanus Raymond couples P. pusillus. This 'species' is represented in Barrande's figures by a complete form 2.4 mm. long (head 1.2 mm.),4 and a cranidium 2 mm. long,5 and so comparable in size with those just described of P. orphanus. Two marked distinctions, however, separate this form from both H. saturnoides and P. orphanus:—the marginal brim in front of the glabella is very wide, instead of narrow; and the thoracic pleure are quite different, having their terminations curved and directed outwards, and so comparing very closely with those of P. rugulosus (which Raymond regards as the final form, not only of this, but also of P. orphanus). P. rugulosus agrees with P. pusillus, not only in the thorax, but in the glabella and in the palpebral lobes which in that species remain long in the adult.6 The only essential difference is in the marginal brim, but Raymond states that the collection of the Museum of Comparative Zoology contains all the stages between the wide-brimmed

¹ Raymond, 1914, p. 228.

² Barrande, 1852. Compare pl. xlix, fig. 5 with pl. iv, figs. 10 & 3 and pl. xiii, figs. 11, 12, 13.

³ Raymond, 1914, p. 228.

⁴ Barrande, 1872, pl. ix, figs. 22 & 23.

<sup>Id. 1852, pl. xiii, figs. 14 & 15.
Ibid. pl. xiii, figs. 3, 4, 6 & pl. ix, fig. 31.</sup>

P. pusillus and the narrow-brimmed P. rugulosus. And he concludes that

'in the development of the brim of *Paradoxides* there is a change from the very youngest where there is no brim to a youthful stage where the brim is wide, then back to a later adult stage in which the brim is again diminished almost to nothing.' (Op. cit. p. 229.)

This diminution of a larval brim was perhaps first observed by Hicks, and shown by Matthew to characterize P. eteminicus Matthew and P. acadicus Matthew. Raymond makes it apply to the genus in general. This however, as we shall see, does not apply throughout. It is inapplicable, at least to an appreciable extent, to the specific ontogenies which include P. orphanus and P. inflatus Barrande.

The diminution of the brim is doubtless connected with the swelling of the anterior part of the glabella—a developmental character peculiarly Paradoxidian and quite opposed to the

characters observed in Olenidæ and Ptychoparidæ.

I may here digress to trace the changing relations between the glabella and the frontal brim. In the early larva, in which little or no brim is present within the marginal rim, the glabella, as in H. saturnoides or in Raymond's larva, consists of four rings, subequal, except that the anterior is the largest. In later larvæ, as in P. pusillus where a brim is present, and P. orphanus where such is absent, it consists of five rings, again subequal, except that the anterior is the largest. In the adult, where the brim is always absent, it still consists of five rings, but the anterior is now $2\frac{1}{2}$ times as long as each of the others. There is thus, throughout development, a great growth, not only of the anterior glabellar lobe, but almost equally so of the cheeks or brim, although the rates of growth at any one time may be very unequal. In P. pusillus and other wide-brimmed larvæ the development of brim has got ahead of the development of the front of the glabella: in P. orphanus and P. inflatus, where no brim is developed in front, the development of glabellar front has kept pace with the development of the cheeks. Later the development of glabella exceeds and overtakes that of the cheeks, the brim where present is lost, and the head-shield in many species becomes angulated in front.

But, if *P. pusillus*, the broad-brimmed larval form, develops into *P. rugulosus*, it is exactly parallel to the development of the forms in the Lower *Paradoxides* Beds of St. John: namely, *P. eteminicus* and *P. acadicus*—long-eyed forms developing from broad-brimmed larvæ. And it would, therefore, appear as if this particular kind of development has obtained throughout the primitive long-eyed forms. *P. rugulosus* is a survival into the newer *Paradoxides* Beds from the primitive long-eyed forms characteristic of the older deposits, and in the probable development of *P. aculeatus* Linnarsson, with a brim and continuous eye-lobe

¹ Salter & Hicks, 1869, p. 56.

² Raymond, 1914, pp. 233-235.

into the long-eyed P. $\"{olandicus}$ S \ddot{j} ögren, we have perhaps the same peculiar development in the most ancient Paradoxides Beds of Sweden.\(^1\) But that it obtains also in some short-eyed forms was indicated by Hicks for P. hicksii, and of this Prof. V. C. Illing\(^2\) has collected abundant evidence not yet described (see

also below, pp. 301, 309).

We can accept, then, the development of the primitive longeyed Paradoxides rugulosus which derives it from the broadbrimmed P. pusillus. It cannot, perhaps, with certainty be traced farther back; but, just as P. rugulosus is so much more primitive than other well-known Bohemian Paradoxides, so is Raymond's larva as much more primitive than the known forms of 'Hydrocephalus' in the elongate form and primitive segmentation of the cephalic axis, as above remarked. It is, therefore, probable that Raymond's larva is an early stage in the ontogeny of P. rugulosus or some similarly primitive form.

Returning to the *H. saturnoides-P. orphanus* line of development, we can, I believe, trace it farther. We can see the same form of thoracic pleuræ in *Paradoxides bohemicus* Bœck,³ In the smallest of Barrande's figures of *P. bohemicus* the head is 4.7 mm. long as compared with *P. orphanus*, 3.4 mm. long: both have a pair of specially long thoracic pleuræ, which is probably the second segment in *P. orphanus* as it is in *P. bohemicus*. The only differences are that the pleural spines protrude somewhat more outwards—a common developmental change, seen for example in *Leptoplastus salteri*; the anterior glabellar furrows have disappeared, and the glabella is a little broader in front; the anterior margin is narrower, and the palpebral lobe is a little shorter. Not one of these changes is reversed: indeed, the last three are carried farther in later development. Thus it appears that an ontogeny may be traced from *Hydrocephalus saturnoides* through *Paradoxides orphanus* to the adult *P. bohemicus*.

Raymond also traces a development from 'H. carens' to 'P. inflatus' Corda, as was claimed by Beecher, stating that they 'make a short series showing the early growth-stages of some as yet unidentified species..., possibly P. behavious' 5

some as yet unidentified species possibly *P. bohemicus*^{7,5} It is the broad form of *H. carens* that must be associated with *P. inflatus*, and of that the largest head-shield is 2 mm. long. Both *H. carens* and *P. inflatus* have the same form of cranidium. *P. inflatus* shows advance in having a second glabellar furrow in the loss of the metacranidial spines, and in the slight shortening of the palpebral lobes. The parial spines issue from points one-third of the length of the head from the back, suggesting (in view of their backward migration during development, characteristic of the genus) that in *H. carens* they would have a still

¹ Linnarsson, 1877, pl. xiv, figs. 1, 2, 3, & 11.

² Illing, 1915, p. 428.

³ Barrande, 1852, pl. iv: compare figs. 10 & 3.

Beecher, 1900, p. 628.
 Raymond, 1914, pp. 231 & 232.
 J. G. S. No. 322.

more forward position, say from the mid-length of the cephalon. In both, the thoracic pleure are of the same falcate form, directed outwards, with which is connected the rising of the metacranidial spines in *H. carens* above them. The first two bear the longest pleural spines; but, whereas in *Hydrocephalus carens* the first is best developed, *Paradoxides inflatus* is advanced in having the first relatively reduced and the second greatly elongated, extending

well beyond the end of the body.

P. inflatus is quite different in its pleuræ from P. bohemicus, with which Raymond doubtfully associates it. On the other hand, P. spinosus has the same form of pleuræ and a short wide glabella. The earliest stage of this figured by Barrande (op. cit. pl. xii, fig. 7) has a head-shield 4.6 mm. long as against P. inflatus 2.4 mm. long. In outline and proportions it is very close to the latter, the only change of note being in the glabella. These changes moreover are of the same nature as those that separate H. saturnoides from P. orphanus, in which case, however, an extra transverse glabellar furrow is already present in the younger form, the change in form being thus a fraction less, while, on the other hand, the change in size is about twice as great. Considering, however, how suddenly the three transverse glabellar furrows appear in the early development of H. saturnoides with hardly any change in size, one need not be surprised at the appearance of two pairs of glabellar furrows in the development of H. spinosus deferred to a later stage. Also, whatever form the adult P. inflatus might take, we cannot imagine it as lacking the glabellar furrows universally present in Paradoxides.

The glabella has changed in shape from spheroidal to pyriform, and just reaches the marginal rim or roll, so that no development of an anterior brim takes places in this species. The parial spines are not quite so far forward, and now are as large as the pleural spines of the second thoracic segment. The palpebral lobes are again further shortened, and not only behind, but (in effect) in front also, owing to the disproportionate enlargement of the

glabella in front.

No change of note can be seen in the thorax, beyond the

addition of segments and a slight broadening.

The development beyond this stage is illustrated by Barrande in no fewer than sixteen figures, which might be extended by the inclusion of the closely related if not identical *P. rotundatus* and *P. imverialis* Barrande. The range in size is from little over 1 cm. to over 26 cm., and if *P. imperialis* be included, perhaps 40 cm. or 16 inches. Throughout this great growth the change in form is relatively small, and is chiefly seen in the glabellar front, the anterior margin, the palpebral lobes, and most conspicuously in the marginal spines. The nature of the change

Barrande, 1852: compare pl. xiii, fig. 18 with pl. xiii, figs. 1-2 & pl. iv, figs. 4-5.
 Ibid. pl. ii, fig. 1.
 Ibid. p. 373.

in the glabella and its relation to that of the anterior margin has

been already discussed in another connexion (p. 272).

The palpebral lobes are further shortened. The parial spines issuing in Barrande's smallest example on a level with the second glabellar lobe take later an increasingly posterior position, ultimately issuing from the level of the occipital segment. The metacranidial angle is thus perhaps straightened out. Another feature is correlated with this backward migration of the parial spine: namely, the backward migration of the anterior ends of the facial suture, which involves also the loci of the procranidial spines. This, however, is more especially marked in P. rugulosus. In common with the other marginal spines the parial spines diminish in length, from an extension to the level of the pygidium at 11 mm. long to half the length of the post-cephalic body (Barrande, op. cit. pl. xii, fig. 1) in an individual 16 cm. long, doubtless continuing to diminish in relative length in larger sizes. The pleural spines of the thorax also diminish in relative length, though this affects especially those of the first and second segments. Those of the first segment, which had been dominant in the later *Hydrocephalus* stage, continue to diminish, but, among the anterior segments even in the largest individuals, they are only surpassed by those of the second. These only attain their maximum in Barrande's P. spinosus of 11 mm. long, where they extend far beyond the pygidium, although already equalled by the parial spines. Thereafter they progressively diminish in relative length, but, as in other Bohemian Paradoxides, even in the adult they exceed those of the neighbouring segments in length, and are matched only by those of segments much farther back. A change of form more important than the shortening affects the pleural spines of the posterior segments. In the youngest stage they are markedly falcate, conforming to the curvature of the spheroidal pygidium; but in the largest individuals they have become straight, and may even be bent outwards instead of inwards.

We trace, then, a development from 'H. carens' through 'P. inflatus' into P. spinosus, another short-eyed form.

Summary.

We may now piece together these more or less fragmentary ontogenies of Paradoxidian forms. Fairly complete ontogenies are limited to Bohemian species, and are made possible by the detailed work of Barrande. We can trace the development of P. bohemicus from 'Hydrocephalus saturnoides' (about 1 mm. long) through 'P. orphanus' into the adult P. bohemicus, up to a length of 15 cm., 150 fold increase; also the development of the largest and most widespread Bohemian species P. spinosus from a 'H. carens' (2 mm.) through 'P. inflatus' into the adult P. spinosus (260 mm.), or, if we include in the same species P. imperialis (400 mm.), a 200 fold increase: both of these are short-eyed forms. We can also trace that of the long-eyed

P. rugulosus from the larval 'P. pusillus', and this perhaps from Raymond's larva¹ into the adult of 120 mm., an increase of at least 120 times. In their ontogeny the two short-eyed forms

resemble one another, and differ from the long-eyed form.

In the more primitive or long-eyed forms little is known of the earliest stages, only one example being known from the older Paradoxides Beds, the 'P. aculeatus Linnarsson', but Raymond's larva from a higher horizon is above identified tentatively with the long-eyed P. rugulosus. In these the glabella approximates to the adult form, being swollen only towards the front, and showing already segmentation into four lobes, the anterior of which has its primitive length—twice as great as the others. In Raymond's larva of 1 mm. head there is no anterior brim, while in P. aculeatus of 2 mm. head there is a moderate brim.

During development, the growth of the cheeks exceeds in rate the swelling of the anterior glabellar lobe, resulting in the temporary development of a wide anterior brim seen in 'P. pusillus', the larva of P. rugulosus, and in all the larva of the long-eyed forms of the St. John Group. This in still later development disappears into the anterior glabellar lobe.

In the Bohemian short-eyed forms the glabella at first is swollen throughout its length and without evident segmentation. After the segmentation into four lobes, the further swelling of the glabella in front, which is accompanied by a lateral shrinking behind, keeps pace with the growth of the cheeks, so that no anterior brim is developed. This, however, is not the case with *P. hicksii*, which develops a brim. Possibly, the absence of a brim in the Bohemian forms may be connected with their *Hydrocephalus* larval stage.

The unique character of 'Hydrocephalus' marks it out as a specialized larval form, in contrast with which the 'P. aculeatus' and Raymond's larva are primitive. Within the geological history of Paradoxides we seem to have, therefore, the introduction of a peculiar larval stage in a group of short-eyed forms—a feature which has numerous parallels among other classes of Arthropods.

As, however, the material is scanty, both types of development

are embraced in the following summary of the development.

The earliest stage known of Paradoxides having not more than three post-cephalic segments is already comparable with the adult, the cephalon consisting of cranidium and free cheeks, and the glabella and palpebral lobes being already defined. Procranidial spines are absent; but metacranidial spines are well developed. Reaching beyond the back of the body they would seem to be dominant, constituting this a proparial stage. The glabella may be uniformly swollen and without evident segmentation ('Hydrocephalus'), or it may approximate to the adult, being swollen only in front, and having already three segmental furrows.

¹ Raymond, 1914, pl. fig. 8.

As the post-cephalic body develops, a transitory pygidium with even margin is first formed. As the segments are released from this into the thorax the first two are furnished with abnormally long pleural spines, the anterior pair of which are at first dominant among the body-spines. Later the second pair become dominant, by which time the metacranidial spines may have disappeared ('P. pusillus'). Early in the Holaspid Period (P. spinosus, P. bohemicus), or before (P. rugulosus), the parial spines assume dominance, owing to the reduction of the second thoracic, which may be later reduced to equivalence with the other pleural spines. The parial spines have then almost their greatest relative length, and thereafter diminish.

At their first dominance the parial spines may have attained the adult position (P. bohemicus), but usually are farther forward (P. spinosus and P. rugulosus). In this case—the more primitive condition—the border of the free cheeks is lateral in position, and divided into two approximately equal parts by the parial Later these spines take up an increasingly posterior position, accompanied by a similar migration, although less in extent, of the anterior branches of the facial suture. There is thus a revolution of the outer part of the free cheek around the palpebral lobe. The posterior branch of the suture, however, takes no part in this movement, ending always opposite the base of the pleural spine of the first thoracic segment, the position being perhaps fixed by the muscular connexion between the posterior segment of the head and the anterior segment of the We have thus a marked shortening and change of direction of the posterolateral margin of the free check, and a great extension of its anterolateral margin, accompanied by a moderate revolution of the loci of the procranidial spines, but no change in the loci of the metacranidials.

During the development of the thorax the lateral lobes of head and thorax increase in width relative to the axis, but to very different amounts in different species; much in P. rotundatus, very little in P. bohemicus. Closely connected with this is the development in most species of a very perfect falcate form for the thoracic pleuræ (P. rugulosus. P. spinosus), from which again the adult often departs, especially in old age (P. spinosus, P. imperialis). This form is not developed in P. bohemicus.

In contrast with Leptoplastus, axial spines in Paradoxides are only represented by vestiges. Matthew records the reduction during development of the occipital spine. Perhaps the large size and the particular mode of life made them unnecessary.

Accompanying the various changes in the spines are two other series of changes: (1) in the glabella and frontal margin; (2) in the eyes and palpebral lobes. These seem quite independent one of the other and of the changes in the spines, for they are far from running parallel to each other in the various species.

Besides the occipital furrow, universally present, the three furrows which typically mark the segmentation of the glabella of Trilobites may be present in the earliest-known stage (long-eyed forms); or, where the glabella is uniformly swollen, they may be quite absent (Hydrocephalus); appearing later, either soon ('H. saturnoides'=P. bohemicus), or late (P. spinosus).

The last to appear is the anterior or fourth pair, suppressed in most trilobites and sometimes in this (*Paradoxides bohemicus*). Their general persistence in the genus is doubtless connected with

the swelling of the front of the glabella.

In all Paradoxides the cephalic axis attains ultimately a large club-like form, mostly due to the great increase in size of its

anterior segment.

This swelling is accompanied by a forward growth of the adjoining parts of the cheeks (doubtless correlated with the widening of the pleural regions), which may be effected before the frontal swelling, and form a wide anterior brim; in other cases, it only keeps pace with it, and nearly always lags behind in later stages, giving to most species an angulated front in old age.

The palpebral lobe (which in early stages issues, in front, clearly from the glabella) loses its evident connexion with this in later stages. But in this genus it is, in front, always opposite the same segment of the glabella: namely, the second of the six dorsal segments. Hence, with the late swelling of the first glabellar lobe, the palpebral lobe diminishes in length relative to the glabella. Behind, in all the early larvæ, it adjoins the metacranidial spine; and in the longest-eyed forms it retains the same relative position during later development. But in shorter-eyed species throughout development it withdraws from this position inwards and forwards by varying amounts, and so becomes greatly shortened in some forms (P. bohemicus, P. davidis). The free cheeks are thus greatly widened, and a long posterior branch of the facial suture develops.

The early stages of development have already been compared with those of *Leptoplastus*, and regarded as indicating a derivation

from the same Heptacicephalic ancestor (pp. 270-71).

But, already in the earliest-known stages, the divergence between the two families is apparent. On the one hand, we note the swelling of the anterior glabellar lobe, even in the most primitive Paradoxides larva; and, on the other, the narrowing of the same lobe in L. salteri. This initial difference is enormously increased by subsequent development. Nothing corresponding to the Hydrocephalus larva of the short-eyed Paradoxides appears in the development of Leptoplastus salteri, and in this case the divergence between the families is much greater.

Another striking difference is in the eye: long or primitive in the one, extending back to the occipital segment; concentrated,

anterior in position, and thus specialized in the other.

A marked difference is in the development of a wide marginal brim in the long-eyed forms; but this is matched in another section of the Olenids (*Protolenus* and *Olenus*), where it persists to the

adult. It indicates parallel evolution within the two families

(see also p. 301).

The difference, too, in the disposition of the parial spine, which here (as normally) continues the outline of the cheek, is again matched in the same section of Olenids.

Divergence also obtains in the dorsal spines. Paradoxides exhibits the last stages of their atrophy, Leptoplastus salteri their

strong development.

Ventrally, they differ not only in the form of the hypostome, but in the hypostomial suture, present in the one, obliterated in the other, and in the connecting sutures across the doublure, widely separated in *Paradoxides*, and corresponding, as primitively, with the dorsal sutures, though apparently coinciding one with the other in the mid-line in Leptoplastus. Figs. 4 & 4a, Pl. XV, illustrate the disposition of parts in the adult Paradoxides, and enable comparison to be made with other types of Trilobite cephala.

As in Leptoplastus a phylogenetic significance is claimed for the successive stages of the ontogeny, so must this in general be

the case for Paradoxides (see below, pp. 309, 315).

VIII. THE ONTOGENIES OF PHACOPIDÆ, AND THEIR RELATION TO PARADOXIDE.

The Phacopidæ being 'Proparia', a comparison with a member of this family may seem to be irrelevant; but in Dalmanites the glabella is so very close, in outline and in its segmentation, to that of Paradoxides, as is also the palpebral lobe, that, in view of the relationship just noted between Leptoplastus and Paradoxides, we may consider whether a measurable relationship may not obtain also with this family. Both Dalmanites sensu late and Paradoxides are large trilobites of similar body form, and with crescentic eyes directed round the whole horizon. Their hypostomes, too, though extended in different directions are sufficiently alike: both have posterolateral points and both seem to have two pairs of maculæ (Pl. XV, figs 3, 3a, 4, & 4a).

The relationships between the different genera of the Phacopidae have lately been the subject of special study, especially by Hærnes, Reed, and Wedekin. The phylogeny within the group has been worked out in some detail, and all agree in regarding as relatively primitive the genus Dalmanites sensu lato, and as the base of this-the subgenus Dalmanitina Reed. Of a species of this subgenus, namely, D. socialis Barrande, we have a very complete

development available.

¹ Barrande was evidently in error in his interpretation of the ventral sutures in Paradoxides. He supposed that the epistome had disappeared, and that the hypostomial suture had come to coincide with the anteromarginal suture; and hence that the connecting sutures connecting these did not exist in Paradoxides. Thus, the part of the doublure which comparisons show to be the epistome he interpreted as part of the hypostome. See Barrande, 1852, p. 119.

Still more primitive Phacopids than the last-named have been described, but the ontogenies of these are not yet known. Perhaps the most primitive is figured by Dr. F. R. C. Reed from the Llandeilo Beds (Balclatchie Group) of Girvan, and named Pterygometopus hunteri Reed. In this the palpebral lobes are long and narrow, reaching back to the posterior intramarginal furrow, and so approaching both in form and in extent those of Paradoxides larvæ and adults of long-eyed species; the glabella shows the 'anterior lobe' subdivided into a front or median and two lateral lobes, the cephalic axis by this exhibiting a segmentation into six segments as in Paradoxides; while again the pleural lobes of the thorax (in the crushed condition of the fossil) are each only half as wide as the axis. Each of these characters has above, by ontogeny, been shown to be primitive. On the other hand, in the form of the middle glabellar lobes it is less primitive, approaching Chasmons.

The Ontogeny of Dalmanitina socialis Barrande, and its Comparison with Paradoxides.

Development of the Cephalon.

The development of *Dalmanitina socialis* was very completely traced by Barrande, who describes and figures fifteen complete individuals in different stages of growth, from a form 0.75 mm. long with two post-cephalic segments forming a pygidium, to an adult 37 mm. long with eleven thoracic and eleven pygidial segments.²

The first stage known is described as 'discoid', and perhaps represents a hemispherical shield. Nearly three-quarters of its length is head, on which the axis is well marked and club-shaped, as in the larval *Paradoxides* figured by Raymond; but the glabellar furrows are in pairs, not united across. Again, the anterior segment is the longest. The lateral margins of the head are continued back into spines, comparable in position and development with the metacranidial spines of 'Hydrocephalus'.

The relation, however, of these spines to the eyes is quite different: the palpebral lobes instead of being fillets extending from the glabella to the spines are knob-like projections at the anterolateral margins of the 'disc'. Probably the eyes are not truly marginal in position, the rim of the shield being buried in the rock. The eyes are thus as short in proportion as the most advanced adult of *Paradoxides*, but take an anterior position as in the larval *Leptoplastus*, *Sao*, etc.

During later development these head-spines of the earliest larva persist to the adult. The eyes migrate backwards and inwards past the mid-length of the head, bringing with them the posterior branch of the facial suture, while in front of the eye a suture is seen in later stages to circumscribe the glabellar front.

¹ Reed, 1914, pl. viii, fig. 8.

² Barrande, 1852, p. 552 a & pl. xxvi, also pls. xxi, xxii, xxvii.

As the pygidium and then the thorax develop, the pleural spines of the post-cephalic segments repeat the form and direction of the head-spines, and thus indicate their homology with these. This is further supported by the position of the facial suture cutting the lateral margin. Thus the head-spines of the adult Dalmanites are to be homologized with the metacranidial spines of the Cambrian forms already considered, and not with parial spines; and the genal spines of the 'Proparia' are quite different morphological structures from those of the 'Opisthoparia'. Dr. C. D. Walcott was, I believe, the first to publish this opinion. I had, however, announced the same view at the Birmingham Natural History & Philosophical Society in 1909, when comparing 'Hydrocephalus' with Dalmanites. Thus this genus and inferentially all the true 'Proparia' retain the metacranidial spines in their primitive position, and in respect to this are more primitive than the 'Opisthoparia', in which the parial spines take over their position and function. It has been assumed by several writers that the 'Proparia' are descended from 'Opisthoparia', presumably by shifting of the suture to the other side of the genal spine. genal spines of these two groups being however, as is here claimed, quite different morphological entities, such a derivation is impossible; and we must derive both groups from the same Heptacicephalic ancestor by the specialization of one or another pair of head-spines and atrophy of the others. The surprising course of this specialization is indicated in the ontogenies of several families (pp. 259, 276, 307), and is summarized below (p. 314).

No traces of parial or procranidial spines appear in the known development of *Dalmanitina*; they were perhaps early lost in the ancestry. In respect to head-spines the larva thus seems comparable with the young 'Hydrocephalus', in which also the procranidial spines are already lost and the metacranidial are

present and probably dominant.

The strict homology between the eyes of different groups of Trilobites is generally accepted, so there is no need to give the several reasons for homologizing the eyes of larvæ of Dalmanites, Paradoxides, and Olenidæ. But the eye of the D. socialis larvæ presents an extreme contrast with those of Paradoxides larvæ both in form and in position. Its compact form is an advance upon the long arcuate form of the other. But its position at the anterior margin of the 'disc', also a specialization, is limited to early larval stages, the adult having its eye high up on the cheeks, as in the adult Paradoxides. Beecher regarded the position in this and some other larvæ as primitive, and based upon it his theories of the phylogeny of the Trilobites.

The 'Hypoparia', in which he supposed the eyes to be ventral, had given rise to forms in which the eyes were at the anterior margin, and thence to forms with the eyes continuously farther back on the dorsal surface.² But, from considerations already

¹ Walcott, 1910, p. 237.

² Beecher, 1897, pp. 101, 181.

given, I regard this theory as quite untenable, while a widely different interpretation is ready to hand. It is unfortunate that Beecher, basing his classification so largely on the eyes, had not recognized as most primitive the eyes of the Mesonacidæ and Paradoxidæ. The trilobites in which the larvæ have their eyes far forward are all trilobites which in regard to eyes are more advanced than the families just mentioned. They belong to the Olenidæ, Ptychoparidæ, Proetidæ, Odontopleuridæ, Phacopidæ. Even in the larvæ the eyes are already concentrated, instead of having the long arcuate form of the larval Paradoxidæ and Mesonacidæ. Hence they are more highly organized, and their forward position is one of specialization, adapting them to be used under the free-swimming conditions of the larval existence (as first pointed out by Prof. L. Dollo 1), in contrast with the slow-crawling conditions of the adult, for which the eyes have a more posterior position well raised above the mud-line, and capable of surveying the whole horizon. Thus the forward position is a larval, not an ancestral character, and may have been introduced in some of them since Middle Cambrian time.

While, regarding the homology of the eyes, there has been general agreement, some students of Trilobites do not seem to have felt so sure regarding the dorsal facial sutures which define the free cheeks. Beecher, for example, regarded the free cheeks where continuous, as in Dalmanites, as an anterior oculiferous segment, and where discontinuous, as is more usual, as the 'pleuræ of an oculiferous segment otherwise lost'.2 But, in the same paper, he speaks of the free cheek cutting off more or less of 'the pleura of the occipital segment' in the 'Opisthoparia'3; while in the 'Proparia' 'the pleuræ of the occipital segment extend the full width of the base of the cephalon'. Thus, while regarding the free cheeks as constituting an oculiferous segment, he homologizes also the genal spines of his 'Opisthoparia' and 'Proparia', in each case the pleural terminations of the occipital segment. But the two are incompatible. If the first is correct, the facial suture would be a morphological entity and the posterior boundary of this segment, and so would be homologous wherever found; if the second, it has a variable position, and is only analogous. Now, however, with the recognition that the genal spines of Dalmanites are metacranidial, while those of Paradoxides are parial spines, there is little reason to doubt the strict homology. at least of the posterior branch of the facial suture, in different trilobites. Regarding the anterior branch of the suture in these two trilobites, a comparison leaves no room for doubting that the pre-ocular continuous suture of Dalmanites represents in Paradoxides the anterior branches of the suture plus the anteromarginal suture, which meets them at right angles. These angles of the cranidium are the loci of the procranidial spines, and are not

Dollo, 1909, p. 410.
 Beecher, 1897, p. 95.

³ *I bid.* p. 101.

improbably represented in *Dalmanites* by the points of sharpest curvature of the suture on either side of the anterior glabellar lobe (see Pl. XV, figs. 3, 3a, 4, & 4a). Thus in this genus the loci of the procranidial spines have migrated over the cheek owing to a transference to the dorsal surface of part of what is in other trilobites the epistomial section of the doublure (see below, Dorsoventral Redistribution, p. 320). A similar transference seems also to have taken place behind this along the border of the cheeks (Pl. XV, fig. 3).

Comparison of *Dalmanites* and *Paradoxides*. (Pl. XV, compare figs. 3 & 3 a with figs. 4 & 4 a.)

Thus we can confidently homologize all the features of the cephalon of *Dalmanites* with corresponding features of *Paradoxides*. Comparison between them shows that:—

(1) Dalmanites has developed the metacranidial spines as genal spines, which were perhaps the dominant spines of an ancestor, as they are in the early larva of Paradoxides and of the Mesonacidæ (see below, p. 307); while it has lost the procranidial, and also the parial spines which Paradoxides develops into its genal spines.

(2) In *Dalmanites* the procranidial loci and the anteromarginal suture (by means of the relative growth of neighbouring parts) have migrated from the margin of the cephalon towards the glabella. And, with the loss of the parial spines, the loci of these have likewise migrated on to the dorsal surface; while the external parts of the posterior branches of the facial suture have migrated forwards.

In Paradoxides, on the other hand, the persistent parial spines migrate backwards to occupy the position and take over the function of the suppressed metacranidial spines; while the loci of the progranidial, together with the anterior branches of the facial suture, migrate outwards: that is, in the same direction. In each case the changes are harmonious, but are in different directions in the two families.

(3) In *Dalmanites*, with the migration of the anterior sutures just mentioned, the normally ventral continuations of the facial sutures across the doublure—the so-called connecting-sutures—have disappeared. Probably they migrated towards the ventral mid-line (compare Ptychoparidæ, Olenidæ, Asaphidæ), but as they were unnecessary for ecdysis (owing to the posterior branches of the suture being in front of the genal angles) ankylosis occurred along them. The hypostomial suture, on the other hand, is retained.

In *Paradoxides* on the contrary, where the parial spines are retained, and the posterior branches of the suture cut the back of the cephalon, the connecting-sutures are retained; but, as the anteromarginal suture preserves its marginal position, the hypostomial suture is lost (see footnote, p. 279).

In each case what is retained is what was sufficient

and necessary for ecdysis.

The foregoing interpretation of the relation between these forms is indicated graphically by the shading in figs. 3 & 4, Pl. XV;

see also the description of that plate, pp. 319, 320.

When we combine with the series of homologies above deduced the resemblances mentioned at the outset (namely, the almost identical glabellar form and the closely comparable hypostomes), there seems to me reason for closely associating these forms, the one accounted a very primitive Opisthoparian, the other an advanced Proparian: that is, from the opposite ends of the reputed Trilobite tree; more closely associating them than Paradoxides can be associated with, say, the Conocoryphidae, Ptychoparidae, and Asaphidæ, other Opisthoparians, or Dalmanites with the Cheiruridæ and Encrinuridæ, other Proparians. And, as the characters of both genera are to a large extent combined in the larva of Paradoxides, the ancestor to which this points may well be the ancestor also of Dalmanites.

The facts suggest that in this Phacopid line of descent the programidial spines were lost earlier than in the Paradoxides line, and, the parial being also lost, the sutures in front, being no longer controlled by functional spines, were then free to migrate by differential growth of adjoining parts. But Dalmanitina is much later than Paradoxides, and the development of its Mid-Cambrian ancestor would doubtless be very different from that of the Mid-Ordovician D. socialis, and may have approached much more closely that of Paradoxides. For, as we have already noted in regard to the eye, the larval Dalmanitina is much more distant from either Paradoxides or its larva than is the adult. Furthermore, the free cheeks of the larva are greatly diminished and anteromarginal in position, which means on my interpretation that the ends of the pleuræ of its occipital segment are forwardly extended to the level of the front of the glabella, and that the loci of the parial spines are also shifted round to the front. Comparisons indicate that these are not ancestral but larval traits, directly connected with the anterior position of the eye of the larva; and they suggest for this larva a very active mode of life, which may have been widely different from that of Hydrocephalus. On the other hand, the close similarity in form of the adult Dalmanites and Paradoxides suggests that these had an almost identical mode of life. It is indeed possible that it was largely the use of the dorsal eyes by the more active trilobite larva that caused these organs to change their form, as well as their anterior position in the larva. The compound eye is the Arthropod eye, and so of later origin in the phylogeny than the hypostomial maculæ interpreted as eyes by Lindström. Hence the compound eve would be of later origin in the ontogeny, as still obtains in recent Crustacea.

It is, therefore, quite reasonable to suppose that the earlier Trilobites in different lines of descent, for instance, Paradoxidæ, were dependent to a later larval stage on the hypostomial eyes; while in later forms, owing to the earlier inheritance of the compound eye, it came to be available for larval use as in D. socialis. On the other hand, in some Phacopids as, for instance, Pterygometopus hunteri, the compound eye is so primitive that it may not have been available in the early larva. There is, therefore, some reason to believe that within the geological history of the Phacopidæ there has been the introduction of special larval characters. This calls to mind the case of 'Hydrocephalus'.

The Development of the Thorax and Pygidium in Dalmanitina.

This follows a simple course which is not, however, without interest. In the earliest stage the two post-cephalic segments are without pleural spines, as is the case in the early stages of 'Hydrocephalus'. Thereafter, and while the segments of the thorax are being liberated from the pygidium, the pleuræ of the latter are furnished like the thoracic segments with pleural spines; but, by the end of the Meraspid Period, the pygidium becomes entire, the total number of pairs of spines in thorax and pygidium at no stage exceeding 11, the number of segments in the thorax of the adult.

While the first five thoracic segments are liberated, the pygidium is limited to three segments, and growth is small, from 1.0 to 1.3 mm.; this may be reminiscent of a micropygous stage in its ancestry, comparable with that seen in 'Hydrocephalus' or Paradoxides. Thereafter the pygidium rises to six or seven segments, and the thorax then grows to the full number: this may perhaps point to another stage in its ancestry. Lastly, the pygidium increases to eleven or thirteen segments.2

IX. THE MUTUAL RELATIONS OF SOME OTHER 'PROPARIA' AND 'OPISTHOPARTA'.

If, in regard to the nature of their genal spines, the Proparians are more primitive than other Trilobites, they may be expected to occur among the Lower Cambrian fossils, and to have had an extensive pre-Cambrian existence. It is, therefore, not surprising to find several genera from the Middle Cambrian as recorded by Dr. C. D. Walcott.

If it be agreed that there is reason to relate the Proparian Phacopids and the Opisthoparian (or Mesoparian) Paradoxides through a common ancestor represented by the larva of the latter, other 'Proparia' may be similarly related to other 'Opisthoparia', and the two groups might both be polyphyletic. Such a suggestion is strongly supported by the Cambrian Proparians described by Walcott, as well as by the characteristics of those previously known. It is generally recognized that affinities among Trilobites are best indicated by the head-shield, and especially by the

¹ See Gürich, 1907, p. 133; also Swinnerton, 1915, p. 542.

² An interesting comparison may be made with Leptoplastus; see ante, p. 247, last paragraph. ³ Below, p. 311.

glabella. If this be applied to the new genera Menomonia, Dresbachia, and Norwoodia,1 their heads, apart from the position of the suture, are those of the Ptvchoparidæ, suggesting close affinity with that family. Another genus, namely, Millardia,2 placed by Walcott in the same family of Menomonidæ, compares closely, except for the position of the suture and the presence of eyes, with the Conocoryphid Ctenocephalus; and a like conclusion offers itself. Thus, I believe that, from the early Ptychoparid, furnished with both metacranidial and parial spines, two scions have sprung: —a more primitive, represented by these Proparial Ptychoparians; and a more advanced—the Ptychoparidæ. Likewise from the early Conocoryphid, similarly furnished, arose two scions :- a more primitive, embracing this Proparian Conocorvphid Millardia; and a more advanced—the Conocoryphidæ. This suggested relationship finds support in the development of the Conocorvphid Ctenocephalus (Harttella) matthewi (Hartt) referred to on p. 259, where, in the earliest stage, the metacranidial spines are dominant, constituting a Proparial stage in the ontogeny of this Opistho-

It is perhaps more probable that these forms (though divided, in accordance with Beecher's classification, between 'Proparia' and 'Opisthoparia') are closely related by common descent, than that they acquired their peculiarity by parallel development; for, not only have almost all investigators regarded the form of the glabella as the most reliable test of affinity, but the Heptacicephalic ancestor to which the ontogenies of so many Trilobites point had already within itself the characters both of 'Opisthoparia' and of

'Proparia'.

X. THE ONTOGENIES OF MESONACIDÆ.

The family Mesonacidæ Walcott includes the genera similar in structure of head to Olenellus. Their most peculiar features are the absence of a facial suture notwithstanding the presence of long arcuate eyes, and their simple pentamerous cephalic axis with a long anterior glabellar lobe. Comparison between their ontogenies and that of L. salteri and of Paradoxides sheds light on the structure and relationships of this unique family, and Dr. Walcott's Monograph on 'Olenellus & other Genera of the Mesonacidæ' furnishes the means of readily making such comparisons.³ All the Mesonacidæ, except Olenelloides, have a more or less semicircular head-shield, with genal spines which have been assumed to be homologous with the similar spines of the Paradoxidæ and Olenidæ. Indeed, several writers have regarded the Paradoxidæ as descendants of the Mesonacidæ.⁴

 $^{^1}$ Walcott, 1916, pp. 161, 166, 168 & pl. xxvi
, figs. 4, 4a,5, 5 $a\colon$ pl. xxvii ; pl. xxvii
; figs. 1 & 2.

Ibid. pl. xxviii, figs. 3, 4, & 5.
 Ibid. p. 253, & id. 1912, p. 239; Swinnerton, 1915, p. 542.

Besides the genal spines, there are also in the genera Callavia and Holmia and in individuals of some species of Olenellus a second pair, the 'intergenal' spines, situated on the posterior border of the cheeks between the genal spines and the occipital ring. Olenelloides represented solely by O. armatus Peach, if an adult trilobite, is the only one that exhibits three pairs of headspines

Olenelloides 1 proclaims its Mesonacid relationship by its lack of facial sutures, its simple pentamerous cephalic axis and long anterior glabellar lobe continuous with the eye-lobes, its headspines, the enlargement of the third and sixth pleuræ of its thoracic segments, and its minute pygidium. Its three pairs of head-spines have been homologized above with the procranidial, parial, and metacranidial spines of the L. salteri larva. The occipital spine is represented only by a 'sharp minute node'. This species has been regarded as a Mesonacid larva by Beecher.2 The head-shield measures only 2.5 mm. in length, and certainly at this size most Mesonacids being large species are still larval. On the other hand, some (for example, Olenellus lapworthi Peach, which is associated with Olenelloides) have already at this size attained a head-form essentially adult.3 Also, in contrast with larvæ, where the posterior segments are rudimentary and very minute, the posterior segments of Olenelloides are closely comparable in every way with the anterior segments. Contrast it, for example, with larve of about the same size, such as Elliptocephala asaphoides, Pædumias transitans, and Olenellus lapworthi.4 It may therefore be regarded with much probability as essentially adult, and so it was regarded by Peach. If adult, it is extraordinarily primitive or degenerate 5:—in its form, which is narrow and worm-like throughout; in its simply segmented cephalic axis with five lobes; in the elongation of the anterior of these lobes; in its three pairs of head-spines, all greatly developed; in its very narrow thorax; in its enlarged pleuræ of the 3rd and 6th thoracic segments; and in its small pygidium. Here the three pairs of head-spines are about equally developed. In Callavia the intergenal spines are small, and conform to the succeeding first segment of the thorax 6; but in Holmia they are raised above that segment. They are seen also in forms otherwise adult of Olenellus gilberti Meek, O. thompsoni, and Pædumias transitans Walcott 8: in these also the intergenal spines are small, and where development is known they are more prominently developed in earlier stages.

¹ Peach, 1894, pp. 668 & 671.

Beecher, 1897, p. 191.
 Walcott, 1910, pl. xl, fig. 3.
 Walcott, 1910, pl. xxiv, fig. 4, pl. xxxii, figs. 6 & 7, pl. xxxiv, fig. 4, pl. xxxix, fig. 5, & pl. xl, fig. 3.
 Ibid. p. 347.

Ibid. pl. xxvii. fig. 1, pl. xlii, fig. 1, & pl. xxviii, figs. 1, 3, 4.
 Ibid. pl. xxvii, fig. 7 & pl. xl, fig. 15.

⁸ *Ibid.* pl. xli, fig. 1, pl. xxxv, fig. 10, & pl. xxxiv, figs. 1 & 2.

Criteria for Distinguishing the Different Pairs of Head-Spines.

As above remarked, it has been assumed that the genal spine of the Mesonacidæ is a parial spine. But Olenelloides has all three pairs equally developed. This is also the case in the larva of Olenellus gilberti. On the other hand, except in Olenelloides, only one or two occur in the adult Mesonacid. Hence, it is not at all self-evident that the genal spine of the Mesonacid is the parial, and it is necessary to establish criteria by which these morphological entities can be recognized. In the presence of facial sutures the recognition of these spines is easy; but, in the absence of that feature, as here, their discrimination can only be effected by a careful collation of the evidence.

The parial spine.—Where the facial suture is present, the position of this spine between the intersections of the head-margin by the two branches of the suture serves to identify it. In the Mesonacide its position would still be indicated, if the vestiges of the suture were clear throughout. But, although a vestige of the posterior branch can often be traced, the full course of the anterior branch has never been observed. Hence we have to fall back on its serial position as the second of the three primitive pairs of head-spines.

The metacranidial spines, the posterior of the three pairs and nearest the occipital ring, form the posterolateral angles of the cranidium; and so, where vestiges of the posterior branches are fully traceable, they indicate the loci of these spines. They are claimed above (pp. 268-69) to be the pleural spines of the occipital segment. This is inferred from their form-mimicking the succeeding pleural spines of the thorax, and from their position at the same distance from the axis. This has been noted above in the larvæ of Leptoplastus, of other Olenidæ, and of Paradoxides; and is seen more clearly still in Holmia and Callavia. Here not only has it the form and position of a pleural spine, but connecting it with the occipital furrow is the 'intergenal ridge' of Kier, closely comparable with the ridge marking the anterior border of the pleural furrow on the adjoining thoracic segment. Furthermore, in this case there is a vestige of the facial suture—'approximately parallel to the intergenal ridge another fainter line . . . a fine raised line that runs in an arc from the posterior edge of the eye to the posterior margin in front of the intergenal rib'. This was observed by Moberg, who interpreted it as a vestige of the facial suture,2 an interpretation accepted by Kiær. Walcott also arrived at the same conclusion regarding several American forms. Of these two lines, sometimes the one, sometimes the other, can be most easily traced in the Mesonacidae. The intergenal rib is doubtless primitive, being characteristic of all the normal segments of the body:

¹ Kiær, 1916, p. 81.

² Moberg, 1899, pp. 323, 354.

accordingly it is much more conspicuous in early stages of the ontogeny. Its presence proves indeed the metacranidial character of the dominant spines of those early stages. Thus those adults which also it characterizes are, in this respect, more primitive. In most Trilobites it is obliterated, doubtless in connexion with the development of the marginal furrow of the head-shield. The vestige of the facial suture is mostly recognizable in later stages, and often is only present in moulds of the inside of the test. In Holmia kjerulfi the intergenal rib is most conspicuous; in Callavia the vestige of the suture; while in Walcott's beautiful photograph of a larval Olenellus gilberti both lines are conspicuous, as also in Kjerulfia (see Pl. XV, fig. 5).

Being the pleural spines of the occipital segment—the least modified of all the head-segments—the metacranidial spines are primitively in front of, and parallel to, the pleural spines of the adjoining first thoracic segment, and, even when their directions change (as in adult *Holmia*, 'Hydrocephalus carens', etc.), both pairs spring from points at the same distance from the axis, being doubtless controlled by the muscular connexion between head and thorax. A further characteristic, as shown in the following pages, is that in the earliest stages of development of Mesonacidae the metacranidials are dominant, and so far as known may be then the only spines; but they are soon superseded by another pair, and

in the adult are always vestigial or absent.

By all these criteria the intergenal spines of *Holmia kjerulfi*, *Callavia callavei*, and *C. bröggeri*, and the intergenal angles of *Kjerulfia*, are seen to be metacranidials.

The procranidial spines, like the metacranidial, have a definite morphological position. In L. salteri larvæ they occupy the anterolateral angles of the cranidium, anterior to, that is, just within, the anterior branch of the facial suture. In 'Opisthoparia', though hitherto found only in this species, they would readily be recognized, owing to this relation to the suture. The distance between their loci in Paradoxides and some other trilobites is coextensive with a ventral plate (the epistome), which in

that genus is ankylosed to the hypostome.

In the Mesonacidæ not only are there no facial sutures, but seldom has any line been observed that can be accepted as a vestige of the anterior branch of the suture—for instance, Holmia and Kjerulfia; while even this supposed vestige cannot be traced to the margin (see below, p. 303). Hence the recognition of the loci of procranidial spines is not easy. Thus the procranidials within this family can only be readily identified in Olenelloides and in the larva of Olenellus gilberti, where they not only occupy the typical position on the shield, but are, moreover, the anterior of three pairs of head-spines. The dominant head-spines of the Mesonacidæ (the genal spines) occupy a great variety of positions

¹ This, however, does not hold good for Zacanthoides.

between the posterolateral angles (the usual position) and the anterolateral angles—aberrant individuals of Olenellus fremonti Walcott and Wanneria halli Walcott. It is, therefore, not surprising that these should represent in some cases the procranidial spines, and evidence is adduced below for the conclusion that in the Mesonacidæ the procranidials are indeed always represented in the genal spines.

Development of Olenellus gilberti Meek.

As in the ontogeny of L. salteri, so just as clearly in some Mesonacidae there exists a Heptacicephalic Stage. This I expected many years ago, from a comparison of the development of L. salteri with that of Elliptocephala asaphoides described by Ford¹ and Walcott, and of Olenellus 'gilberti', now O. fremonti²; and in his 1910 monograph Walcott proves this for O. gilberti. In his pl. xliii, fig. 6 he figures a beautifully preserved head of this species 1.5 mm. long, in which even the facets of the compound eye are indicated. It is about as wide as long, with a simply segmented axis, and three pairs of marginal head-spines corresponding (as Walcott points out) to those of Olenelloides. The metacranidial spines are the strongest, and the procranidial the least developed. Similar larval head-shields of the same species are figured in his pl. xxxvi, figs. 11, 12, & 14, ranging in length from 1.3 to 2.5 mm. In these, while the procranidial and metacranidial spines occupy the same positions as in Olenelloides and in the larval L. salteri, the middle or parial spines have a more posterior point of origin. Only head-shields are figured and described, and a comparison of these with the adult would at first suggest that the species had, as regards the head-spines, a similar development to that of Paradoxides, with which it agrees in the form (and doubtless in the function) of the genal spines. The younger larvæ constitute a Heptacicephalic Stage comparable with the corresponding stage of L. salteri. This O.-gilberti larva is at present unique of its type among Mesonacid species.

In several members of this genus the position of the 'genal' spines is very variable. Walcott figures O. fremonti as exhibiting them in different positions from the level of the posterior margin forward to the anterior margin, while in other species they vary between the level of the posterior border and a position well in front of this. Regarding this he says:—

'a curious phase in the later development of the cephalon is the advancing of the genal angles from the line of the occipital segment until they are forward of the anterior margin of the glabella.'

But the facts are obviously capable of an alternative interpretation:

¹ Ford, 1877, 1878, & 1884.

Walcott, 1886, p. 169 & pl. xvii; 1891, pp. 176-80 & pl. xx.
 Ibid. pl. xx; or id. 1891, pl. lxxxvi; or 1910, pl. xxxvii.

namely, that the anterolateral spine is the programidial; and their significance can be discussed after other facts have been reviewed.

To Olenellus fremonti, which was only in 1910 separated from O. gilberti, Walcott refers an early larval head-shield 1.5 mm. long, formerly assigned to the latter species. It is closely comparable with the protaspis of the forms discussed below exhibiting only metacranidial spines. He also figures larvæ of O. lapworthi Peach and O. reticulatus Peach, which may be taken as representing successive stages of development.

In the O.-lapworthi larva (head 1.2 mm.) the metacranidial (intergenal) spines are still dominant, but the 'genal' are also present at the posterolateral angles; while in the other (1.5 mm.) the intergenal spines are reduced, directed somewhat inwards over

the thorax, and only just larger than the 'genal' spines.

Development of Elliptocephala asaphoides Emmons.

The development of this form was described by Ford,3 and is reproduced by Walcott with the addition of two stages of the protaspis, 0.8 mm. and 1.75 mm. in length respectively, and of other stages greatly extending Ford's series. The earliest stages are represented by the two protaspids. Each represents only the cephalon. Walcott calls them 'two very small head-shields', and adds that 'as far as can be determined, the thorax is not yet developed in either specimen'.5 In exhibiting the cephalon only they agree with that of a Paradoxides described by Raymond. But, from what is known and inferred as to the development of new segments in front of the anal segment, it is probable that at least this segment, if not some others, lies behind the occipital, possibly extending in a ventral direction. Even the smaller of these protaspids, notwithstanding its youth, is much larger than the head of Leptoplastus salteri in the earlier Meraspid degrees; but this large size is not surprising, in view of the fact that the adult measures about 5 inches in length.

Both the protaspids show posterior spines, which can only be interpreted as metacranidials; and the larger individual shows the palpebral lobe extending to the outside of these spines, as in *Paradoxides* larve. The first stage figured by Ford is represented as being somewhat smaller, and the second as of about the same size as the larger of Walcott's protaspids.

 $^{^1}$ Walcott, 1886, pl. xix, fig. $2\,e\,;$ or 1891, pl. xxxv, fig. $1\,f\,;$ or 1910, pl. xxxvii, fig. 20.

² Id. 1910, pl. xxxix, figs. 6 & 8.

³ Ford, 1877, 1878, 1881.

⁴ Walcott, 1886, p. 169 & pl. xvii; 1891, p. 637 & pls. lxxxvii-xc; 1910, pls. xxiv-xxv.

⁵ Id. 1886, p. 169. In later describing the 'pygidium' of these protaspids as 'a simple plate without axis or segmentation', Walcott is evidently in error. The position of the palpebral lobes shows that the posterior segment is the neck-ring, and its possession of a median node is in support of this; see Walcott, 1910, p. 237

Ford claimed, and Walcott agrees, that the spines of these forms are the united intergenal and genal spines, and that

'the progressive changes of the cephalon result in the gradual separation of the intergenal and genal spines and the straightening-out of the posterior margin.'

Walcott further states (1910, p. 237)—

'this occurs in Pædumias (pl. xxv, figs. 20-22), Elliptocephala (pl. xxv, figs. 9 & 10), and Wanneria (pl. xxxi, figs. 8, 5, 6).'

But, while in Ford's figures (op. cit. pl. xxv, figs. 1 & 2), which Walcott acknowledges as 'somewhat diagrammatic', these spines are represented as double, and in fig. 2 as separate, though lying side by side, in Walcott's very clear and beautifully figured examples the spines are quite simple in individuals of the same size. On the other hand, Ford's figures seem to illustrate later

stages of development than the protaspids of Walcott.

In the next stage the cephalon exhibits, not only intergenal spines behind the palpebral lobes as before, though now apparently simple, but another pair believed to be the future genal spines projecting from posterolateral angles which have replaced a previously rounded contour of the head-shield. Ford believed that these latter spines had migrated outwards from previous conjunction with the intergenal spine; but I would suggest quite a different interpretation, based on a considerable number of facts, all brought forward since Ford's day.

Already in 1877 Linnarsson, on receiving Ford's paper of that year, adversely criticized the interpretation there given, remarking on the peculiarity of such abnormal local growth at the back of the shield. But, attributing both the American Elliptocephala and the Swedish Holmia kjerulfi Linnarsson to Paradoxides, he suggested that Ford's earliest stages represented the cranidium only, and that the free cheeks with their genal spines were missing. This we now see is incorrect, as the Mesonacids have

no facial suture.

The view that first offers itself on considering this development is that Ford's interpretation of the posterior spines in earlier stages has been coloured by what he found in later stages; but a comparison with the development of *Pædumias* from Helena (Alabama), which I have been able to follow through the courtesy of Dr. C. D. Walcott and the U.S. National Museum, suggests quite a different interpretation, which may be here outlined.

Three pairs of head-spines have to be accounted for. In general, in the Mesonacidæ two pairs only are recognized; but, though we might be inclined to homologize them with the parial and metacranidial spines from analogy with *Paradoxides* and other 'Opisthoparia', one may well ask whether programidial

spines are not also represented.

In Paradoxides the parial spines consistently move back during

¹ Linnarsson, 1877, p. 361.

ontogeny, as do also the loci of the procranidial (see above, p. 275). In Elliptocephala too, in later stages, the genal spines are seen to move backwards. Also, if we look at the larvæ of Olenellus gilberti, we see that only at the metacranidial spines does the course of the inner edge of the margin answer to the spines outside; there alone is the simple curvature of the inner edge of the margin much modified. At the parial spines only very slight angulation occurs, while at the procranidial there may be no change of curvature whatever. Thus spines might exist outside the rounded contour of the protaspis of Elliptocephala. over, the adult Mesonacids are very convex, where (as in limestones) the state of preservation allows this to be seen; and there is much evidence already cited for the belief that in early stages the Trilobites were more convex than when adult: thus marginal spines might exist, extending ventrally into the rock, and so remain unnoticed. Furthermore, even if we accept the evidence as indicating that spines other than the intergenals do not exist in the protaspids, there are still three pairs of potential spines to be accounted for in Mesonacid larva, although some may be temporarily suppressed.

With these considerations in mind we may trace the development of *Elliptocephala*. We can take as representing the course of development of the head-shield Walcott's figs. 9 & 10 and Ford's figs. 1–8, all in pl. xxv, op. cit. The earliest protaspids exhibit only one pair of spines, and these may be confidently claimed as metacranidial spines. The next two stages (figs. 1 & 2) exhibit two pairs of spines in close association, and that Ford is correct in figuring two pairs is supported by my discovery of an individual of *Pædumias transitans* with a similar arrangement. These I would interpret as the metacranidial and the parial spines,

which in Olenellus gilberti are near to one another.

In the next stage (fig. 3) behind each palpebral lobe, in place of these double spines, there appear only simple spines, though another spine also appears, coming off from the posterolateral angles of the head-shield, but well in front of the posterior border. In Ford's view these have migrated outwards and forwards from a previous position in contact with the metacranidials, and the latter are now left alone as the spines behind the palpebral lobes. In my view these last are the completely coalesced parial and metacranidial spines, while the posterolaterals are a new pair, the procranidials. They are already dominant, and possibly already existed in the preceding stage (fig. 2), at the points of strongest curvature, which are here interpreted as their loci. These points in the protaspis (fig. 9) are in front of the middle, and in succeeding stages take an increasingly backward position up to fig. 4 of the same plate, when they have, at a head-length of 2 mm., attained the adult position. Thus, in my view, the loci of all three pairs of head-spines are in typical adult Mesonacids crowded on to the posterior border, while in typical 'Opisthoparia' only the

two posterior pairs are thus associated, and in the 'Proparia' the hindmost pair alone. This crowding of the spines on the posterior border would, in the absence of the facial suture, furnish a reason for the coalescence of the metacranidial and parial spines into the so-called 'intergenal' of Elliptocephala.1 On this theory Ford's first stage (fig. 1) is a composite drawing, combining the stages preceding and following fig. 2.

Such a development, though new and strange, appears to me much more reasonable than that assumed by Ford, which involves (1) an antecedent separation of these spines, (2) their approximation, (3) their re-separation: in other words, it involves a reversal of preceding development, besides which, as shown above,

it is entirely opposed to what obtains in Paradoxides.

A character, however, which seems to mark the Mesonacidæ is their variability in the extent and position of the paired head-spines, and, although in these individuals the parial and metacranidial spines seem usually to have coalesced, they may be separate at a much later stage than Ford's fig. 2 of Walcott's pl. xxv. This is suggested in Walcott's fig. 7 of pl. xxiv (op. cit.), where three head-spines are represented as quite separate at the back of the left cheek, although one is very minute. Whether in such an individual the separation of the spines has persisted throughout development, or has been partly brought about by the broadening of the shield, cannot be determined.

In the early part of the Meraspid Period Elliptocephala bears comparison with Olenelloides (and so with the young L. salteri). The cephalic axis is essentially the same, but the outline of the cheeks is modified by the procranidial spines being revolved to the back, where the loci of the three pairs of head-spines are crowded together. The thorax also is essentially the same in the two genera. It is relatively long and narrow, with very narrow pleural lobes, and the pleuræ of the third segment enormously enlarged. The figures of these Elliptocephala larvæ exhibit no enlargement of the pleuræ of the sixth segment; but these excessively minute segments are only dotted in by Ford, indicating their indistinctness.

Thus Elliptocephala passes through a highly modified Heptacicephalic Stage. The characters in which it differs at that stage from Olenelloides are of two opposite kinds. It is both more primitive, in the elongated papebral lobe; and more specialized, in the wide cheeks and posterior position of the parial and procranidial spines. But, in these latter respects, Olenelloides may have suffered reversion.

Naturally, the later development of Elliptocephala follows on lines quite different in many details from that of Leptoplastus, leading towards so very different an adult form; but we may note in both the same change in glabellar furrows, the considerable widening of the head and of the thoracic segments, and the great development in both of posterior dorsal spines.

¹ This, however, does not apply to Holmia, Callavia, and Kjerulfia; see pp. 288-89.

Development of *Holmia kjerulfi* (Linnarsson).

A similar development, though differing in details, is described and figured by Dr. J. Kiær for Holmia kjerulfi. Various sizes of head-shield are represented, from a protaspis 1.25 mm. long to cephala 30 mm. long, the form of the adult being reached in heads of 10 mm.

In Kiær's text-figure 11, p. 67 & pl. vi (op. cit.), five successive stages are exhibited together for comparison. The earliest stage is a protaspis of 1.5 mm. which as he points out, resembles very closely Walcott's protaspids of Elliptocephala; but the axis is much narrower, and its segmentation much clearer. As in Elliptocephala, the anterior glabellar lobe is not apparent,² and the cheeks within the palpebral lobe are 'segmented'. Roughly, the front half is semicircular, the posterior half makes three sides of a hexagon. These sides are all concave, and from the posterior angles project very prominent intergenal spines—clearly metacranidials (see above, p. 289). The sharper curvature at the sides

may indicate the loci of the genal spines.3

The next stage represented is nearly 25 times as large, and much more advanced. The head is shorter in proportion; the intergenal spines are relatively much reduced, and the genal spines are well developed, proceeding from the lateral margin at a quarter of the head-length from the back. In later stages they increase in relative strength, and take up a more and more posterior position as in Elliptocephala. Here we have no means as yet of tracing a third pair of spines, but reasons are given below (pp. 303 et seqq.) for regarding the genal spines as again the homologues of the procramidial spines with which the parials are here coalesced. The spine on the neck-segment, too, was not traced in early stages, but is almost certainly present, being a primitive character in Trilobites as well as a characteristic of the adult Holmia. In one respect the development is in close agreement with that of the long-eyed Paradoxides—the glabella 'increases in breadth and in extent forwards with increasing size', 4 and from the first the anterior glabellar lobe is almost twice as long as those behind (op. cit. pl. vi, fig. 3 & pl. viii, fig. 2).

In the thorax changes take place which are paralleled in Leptoplastus salteri: 'the thoracic segments are narrower in younger specimens than in older ones' (op. cit. p. 60 & figs. 8-9). The small form has very short pleuræ obliquely truncated by fine sharp long spines, as in the young L. salteri. The large form has the pleuræ continued into broader, shorter, and more curved spines,

comparable with L. salteri about Degree 7.

Thus the development of Holmia kjerulfi lends no support

³ Kiær, 1916, p. 66 & pl. vi, fig. 1.

¹ Kiær, 1916, pp. 66-69.

² Note, however, this character in the same stage of Pædumias; see below, p. 300. 4 Ibid. p. 68.

to the theory of the original union and later separation of the intergenal and genal spines, as described by Ford for *Elliptocephala* and accepted by Walcott and Raymond ¹ as characteristic of the Mesonacidæ. Rather it points the other way.

The genus *Callavia* is nearly related to *Holmia*, and it is noteworthy that, for *Callavia bröggeri* Walcott, Walcott records a like succession in the dominant spines. In a head 5 mm. long the intergenal is still the longer.²

Development of 'Pædumias transitans' Walcott.

In all these cases the known development is very far from complete. The form now to be considered is that in which the earliest stages are best represented, namely, 'Pædumias transitans' Walcott; but it is here left until the last, so that its development may be considered in the light of the cumulative evidence yielded by the other Mesonacidæ. I have been enabled, to some extent, to trace and supplement the development recorded by Walcott, thanks to the loan of specimens from the U.S. National Museum.

'Pædumias transitans', at its first presentation and description by Walcott, is represented by a fairly complete series of developmental stages. It is no more than its due: Pædumias is perhaps unsurpassed in interest by any trilobite, for it proves the relationship between the aberrant Olenellus and the more normally terminated Mesonacids, and it helps to indicate the relationship

between the Mesonacids and other trilobites.

Olenellus is apparently terminated behind at the fifteenth post-cephalic segment in a spine-like 'telson'. If this was really the case for any species of Olenellus, Pædumias is transitional in character between the Mesonacids and such Olenellus species. Pædumias transitans from York (Pennyslvania) is clearly very closely related to (if not identical with, or the other sex of) Olenellus thompsoni Hall; but, behind an Olenellus-like body with an axial spine as chief representative of the fifteenth segment, there follow, according to Walcott, from two to six (though no more than three are figured) narrow rudimentary segments, together with a rudimentary pygidium or anal segment.

The development of this form is briefly described by Walcott,³ who, however, almost confines himself to comparing the post-cephalic region, in which he sees, when first this is developed, a 'Holmia stage without enlargement of the third segment and without telson', then an 'intermediate stage with enlarged third segment, but without a dorsal spine on the fifteenth segment', and last the 'Pædumias with large third segment, large spine on the fifteenth segment, and with segments and plate-like pygidium posterior to the fifteenth segment'. But these stages do

¹ Raymond, 1917, p. 207. ² Walcott, 1910, p. 280.

³ Ibid. pp. 307-10.

not correspond with Walcott's own conception of its phylogeny,1 and this ontogeny merits more detailed treatment, especially in the development of the head-shield. Walcott compares the larval head-shields with those of Elliptocephala and Wanneria, and remarks that 'these all prove the close family relationship of the young' of these three genera. He notes, on the other hand, the remarkable fact that the cephalon of the adult Olenellus gilberti is very similar to Pædumias, but in the younger stages of growth they differ materially'. These last we have compared above with Olenelloides, and with the Heptacicephalic Stage of L. salteri.

The development of the cephalon of Pædumias will now be followed, using Walcott's figures in pls. xxxii, xxxiii, xxxiv, & xxv of the 1910 monograph. The nine larvæ represented in pl. xxxii are all from the same locality near York (Pennsylvania), and are preserved in shale. Further, they are of such a character that (except for the thorax of fig. 3) all might well belong to the same species. On the other hand, the specimens figured in pl. xxv are from Helena (Alabama), and exhibit points of difference from specimens of the same size from Pennyslvania (see below, p. 300). The hypostome also, from Alabama (op. cit. pl. xxxiv, fig. 8), having a perforated instead of a denticulate margin, would seem to indicate a different species: so, except for the smallest size from Alabama, the York series will suffice.

In this series, unlike those Mesonacid developments already considered, spines never appear appreciably in advance of the posterior border of the cephalon; while, owing to the long and narrow shape of the head-shield, they are the more crowded together on the

posterior border.

The earliest stage is represented by the protaspis from Alabama (op. cit. pl. xxv, fig. 22). It is 0.8 mm. long, and is comparable with the stage of Elliptocephala of 1.3 mm. It is a roughly circular shield representing, as in that case, the cephalon only. The rounded lateral margins are continued into broad-based spines converging behind. Between these, the rounded outline of the occipital segment completes the circle. The extension of the line of the inner edges of the spines to the occipital furrow indicates that the metacranidial spines are well developed; and, even if the parial spines were also represented coalesced in their bases, their form suggests that the metacranidial spines are dominant.

The next stage is represented by pl. xxxii, figs. 1, 2, & 3 (op. All have head-shields of about 1 mm. The first lacks the thorax, but the others exhibit a thorax which Walcott compares with Holmia as being without enlargement of the third segment. Considering, however, how excessively delicate such minute segments must be, we may well doubt this conclusion, all the more that the enlargement of the third post-cephalic segment appears from Elliptocephala to be a primitive character. All three head-shields have a straight posterior border. Their sides, straight towards the

back, are continued into an evenly rounded front. From the back of each project prominent backwardly-directed spines. Walcott describes these as intergenal spines (op. cit. p. 398), and they may be confidently identified with the metacranidials, because: (1) the smallest of these, 0.9 mm., is so very little larger than the protaspis, 0.8 mm.; (2) they are connected behind the palpebral lobe in fig. 1 with the occipital furrow; (3) they are not much farther out than the palpebral lobe; (4) in other Mesonacids of a similar size the metacranidials are dominant (see above, pp. 291, 295).

In figs. 1 & 3, outside these metacranidials are two points forming the posterolateral angles of the shield. Being the next pair in order towards the front, these points may be accepted as the parial spines already come into position at the back of the shield.

The next stage represented is twice as large as the last, and is illustrated by figs. 4 & 5 with heads of 2 mm. Both are beautifully preserved. In both, the head-shield bears backwardly-directed spines comparable in development with the metacranidial spines of the last stage; but, instead of lying just outside the thorax on either side (fig. 3), they are far removed from it, as seen most prominently in the smaller (fig. 5). Outside these, and forming the posterolateral angles of the head-shield, occur small spines, blunt in fig. 5, sharp in fig. 4. Exactly the same disposition of spines characterizes also heads of 4 mm. (op. cit. pl. xxxii, figs. 6 & 7). At first, one is inclined to see in these spines the metacranidial and parial of the earlier stage; but closer inspection and comparison with other Mesonacidæ suggest quite a different conclusion. In the development of Elliptocephala asaphoides the intergenal spines already in a head of 1.5 mm. are superseded in dominance by the genal spine; while in Holmia kjerulfi the same has happened before the head measures 3 mm., 1 and in Olenellus gilberti about 2.5 mm. and before it attains 4 mm. Hence these dominant head-spines in heads of Pædumias 2 to 4 mm. long are probably not the metacranidial spines. Also, if we examine figs. 5, 6, & 7, in each case we see posterior projections which can be interpreted as the bases of the metacranidials in a natural position opposite the ends of the first segment of the thorax, as in the intergenals or metacranidials of Holmia and the metacranidials of L. salteri. In fig. 5 (right side) it forms a projection which catches the light, and in fig. 7 it seems fairly prominent. It may be objected that, if this be so, the spines are farther in than in earlier stages; but one may see in Elliptocephala that, when the intergenals have lost dominance, they lie opposite the ends of the first segment of the thorax, as shown in Ford's and Walcott's figures. One may recollect, too, how in Holmia kjerulfi and in 'Hydrocephalus carens' the metacranidials override the thoracic pleure.2 Outside the dominant

¹ Kiær, 1916, p. 68 & fig. 11 b, p. 67.

² Compare also 0. reticulatus Peach, 1.5 mm. long, in Walcott, 1910, pl. xxxix, fig. 8.

posterior spines in individuals both of 2 mm. and 4 mm. headlength are, as already mentioned, short spines at first blunt or right-angled, then sharp (figs. 4, 6, & 7). In the next stage, perhaps about the same size as the last (op. cit. pl. xxxiv, fig. 4), these outer spines are the stronger, the inner being greatly reduced; and they increase in relative size through Walcott's fig. 2, pl. xxxiv, of head-length 7.5 mm. to his fig. 1, pl. xxxiv. of head-length 12 mm., while in large adults they are the only spines persisting.

Thus, according to my interpretation, these larvæ of Pædumias of a head-length of 2 to 4 mm. have three pairs of head-spines; but these, instead of being relatively lateral in position (the end members bounding the sides of the cephalon as in Olenelloides, the young Leptoplastus salteri, and Olenellus gilberti), they are all directed posteriorly. Nevertheless, being three pairs and three only, we can with confidence homologize them with the three pairs

of spines in the other forms.

Such an interpretation involves the migration, not only of the parial spines from their primitive position half-way up the sides of the shield back to the posterior border, as seen also in Paradoxides, but even of the procranidial spines from the anterior border to the posterior border of the shield. But to what extent the migration obtained in the life of the individual Pædumias cannot at present be seen. Each of the pairs became dominant in succession, and, as all the spines appear only at the posterior border of the shield, one may well believe that only one pair at a time would be functional, and that the transferences of function and so of dominance would be effected at ecdyses.

If we turn now to the post-cephalic body of these stages with head-lengths of 2 to 4 mm., it consists of seven to twelve thoracic segments and a minute pygidium or anal segment. It is narrow, with narrow pleural lobes, the pleure obliquely truncated, the third segment being greatly enlarged and extended into long spines comparable with the dominant spines of the head. If we possessed better material we should doubtless see the sixth segment also more highly developed than its neighbours. This is certainly the case in the adult Pædumias (see, for instance, pl. xxxii, fig. 10 & pl. xxxiii, fig. 1) and in Olenellus thompsoni (pl. xxxiv, fig. 3).

We can compare this stage, both in head and in thorax, with Olenelloides. It constitutes the Heptacicephalic Stage of Pædumias and also of Olenellus thompsoni. Instead, however, of all three pairs of spines being simultaneously well developed and functional, the parial spines are dominant, and both the other pairs subordinate. What specially marks it is the extension of the morphologically anterior border, and reduction of the lateral, so that the procranidial spines are carried to the posterolateral angles of the shield. This stage is furnished with an extensive anterior brim, which later diminishes in extent as the cephalon changes its form to short and broad. This recalls similar changes in certain Paradoxides already mentioned (p. 272).

When fifteen thoracic segments are acquired, the dorsal spine of that segment begins to develop, and with a head of 4 mm. (op. cit. pl. xxxiv, fig. 4) may be already prominent. At the same time, the procranidials have become dominant on the head, and form the genal spines, while the parials have become reduced, and form the

'intergenals'.

Thus, in different Trilobites, the genal spines are of diverse They may be constituted by the metacranidial spines, as in Proparian Trilobites; the parial, as in the Opisthoparian; and the programidial, as here in the Mesonacide. The intergenal again may be the metacranidial, as in Holmia and Zacanthoides; or the parial as here. In the Mesonacidæ, however, with the crowding of the spines on the posterior border there is a tendency to coalescence of spines: and so in Elliptocephala the intergenal is probably a coalescence of the two posterior spines; while in Holmia and Callavia the genal is probably a coalescence of the procranidial and the parial (see below, pp. 303-306). Furthermore, the dominant spines of the head (in other words, the genal spines) may be successively in the same ontogeny: first the metacranidial, then the parial, and lastly the procranidial, as shown above.

The parial spines continue to be reduced to complete suppression on large individuals, and the narrow segments behind the great dorsal spine on the fifteenth thoracic segment are on the way to suppression, though whether this has obtained in Olenellus

thompsoni may well be doubted.

Already Walcott, from more perfect material, has claimed 'Olenellus gilberti' as a Mesonacis, a genus which differs in no essential character from Pædumias. Thus all three genera may well be united within the genus Olenellus, under which name was described the first-known of these-O. thompsoni. At the most, they do not merit a higher than subgeneric rank under Olenellus.

On slabs of decalcified Montevallo Shales from Helena (Ala.) lent to me from the U.S. National Museum, and bearing Pædumias in early stages, several interesting features are exhibited. Only head-shields are represented, and they parallel the series from

Pennsylvania discussed above.

The anterior glabellar lobe is early developed. It is bent down to the front following the slope of the cheeks, and is about twice as long as those behind it. It is hardly seen in a specimen lighted from the front. This anterior lobe, as also the other segments of the cephalic axis, exhibits in early stages conical projections from the back of each, indicating suppressed axial spines. Opposite these on each side, and within the palpebral lobes, are still more prominent cones, those on the two posterior segments directed backwards. These may, not improbably, be homologous with the similar points figured by Walcott on the pleuræ of the thorax of Callavia bröggeri Walcott,2 and present also in Callavia callavei (Lapworth).3

¹ Walcott, 1917, p. 66 & pl. ix, fig. 4.

² Id. 1910, pl. xxv, fig. 21 & pl. xxvii, fig. 5. ³ Lapworth, 1891, pl. xiv, fig. 16.

The development of the wide brim in front of the glabella, and its subsequent rapid disappearance, is strikingly shown. It is as strongly marked as in the Pennsylvanian series, and, when the brim is being reduced, development seems to be accompanied by an

actual shortening of the head-shield.

The head-spines are of especial interest. In the earliest stage the metacranidials are the only spines seen. In a later stage one head 1.3 mm. long exhibits a stout spine, obviously double, consisting of an inner stronger spine, along the outer side of which is attached a thinner shorter spine. These may be interpreted as the metacranidial spine still dominant, but having the parial coalesced with it. This double spine recalls the condition described and figured by Ford for *Elliptocephala asaphoides*.

XI. THE FACIAL SUTURE OF THE MESONACIDE.

What is most surprising in this ontogeny of Pædumias is the appearance of the programidial spines at the posterolateral angles of the shield. For, if the anterolateral points of the head-margin be the primitive position of these spines, as indicated by the anterior branch of the facial suture in both 'Opisthoparia' and 'Proparia,' their presence at the genal angle involves their migration back through the whole length of the head-shield, at least in the phylogeny, if not in the ontogeny, of Mesonacid species. some species (for example, Olenellus gilberti) it probably does occur also in the development, and this may be the case in all. Further, if the facial suture be a primitive feature of the Trilobite cephalon, it involves the rotation of the anterior branch of the suture, back through the length of the head-shield. Thus, on this view, the external margin of the free cheek is rotated round to the rear, and is represented in the adult Mesonacid by a short length of the posterior border within the genal spines.

In this connexion the history of opinion on the sutures of the Mesonacid is of importance, and may be briefly outlined. According to Walcott, in the case of Olenellus gilberti Meek, as also in that of O. howelli Meek, identified with it by Walcott in 1886, the figures which accompany the description of the species by White in 1875 show the courses of sutures, but no reference to them occurs in the description. Whitfield next in 1884 gave a description of a suture behind the eye in O. thompsoni. Walcott in 1886 showed that these supposed sutures did not exist, being based on cracks running from the back of the eye directly to the posterior margin. At the same time, he figured and described the type-specimens of O. gilberti as having sutures in front as well as behind the eye. The anterior branch was described erroneously as running out to the anterior margin 3; but, regarding the posterior

¹ Walcott, 1886, pp. 164, 176.

Whitfield, 1884, pl. xv, fig. 1,
 Walcott, 1886, pp. 163, 172.

branch, he gives the experience of himself and Ford that the 'head-shields fractured as easily in one direction as another,' and says (1886, p. 164):—

'We invariably find [in O. thompsoni] the line of the suture running obliquely outward, and terminating at or very near the pleural angle [that is, opposite the geniculation of the pleural lobe of the thorax].... In uninjured casts of the interior of the test of the head [presumably of O. thompsoni and O. gilberti], the direction of the suture is indicated by a slightly raised line from the eye back to the pleural angle.'

He believed in the existence of a real suture along this line in

early stages.

In 1887, Holm's exhaustive study of *Holmia kjerulfi* showed that, while no dorsal sutures occurred in that species, a ventral intramarginal suture existed, cutting off a doublure of semi-annular form, to which the front of the hypostome was immovably attached.

Walcott's matured opinion regarding the condition in *Olenellus* was given in his 'Fauna of the *Olenellus* Zone' 1891, p. 635, when he proposed the family name Mesonacidae, distinguishing it from the Paradoxidae by the 'absence of sutures'.

On p. 633 (op. cit.) he writes of Elliptocephala, 'what I had identified as the facial suture is a raised line in the cast of the interior of the shell that fills a depressed line occupying the position of the suture'. Later (1910, p. 327), he states of Olenellus gilberti that the suture

'extends outward from the posterior base of the eye, and crosses the posterior border obliquely so as to terminate at the intergenal angle, or is continued into a short spine. This ridge follows the line of the facial suture which is probably in a condition of symphysis; no traces of the facial suture have been observed in front of the eye,'

Such suggestions of a posterior branch of the suture he records for ten species belonging to seven genera of the Mesonacidæ, and he points out the resemblance in direction to that obtaining in *Paradoxides*.¹ But he, nevertheless, veered round to the opinion that the facial sutures were 'rudimentary, or in a condition of synthesis', and in this family had not yet appeared.² This later view was also adopted by Swinnerton.³

Two entirely distinct lines, however, are often present behind the eve in Mesonacids, as observed by Moberg, the one representing the suture, the other being the intergenal rib of Kiær, which is interpreted above as the anterior limit of the pleural

furrow of the occipital segment. (See p. 288.)

¹ Namely: -Elliptocephala asaphoides, Mesonacis vermontana, Callavia broggeri, C. bicensis, Holmia rowei, Wanneria gracilis, Olenellus thompsoni, O. canadensis, O. logani, and Peachella iddingsi.

Walcott, 1910, p. 236; see also above, p. 286.
 Swinnerton, 1915, p. 542 & 1919, p. 110.

There is thus a good measure of agreement as to what represents the posterior branch of the suture. Turning now to the anterior branch, the early figures of which were subsequently shown to be fictitious, Moberg (in 1899) was the first to describe what may be accepted with much probability as a vestige of it. In Kjerulfia lundgreni (Moberg), he describes the occurrence of

'fine upraised lines running out from the foremost part of the eyes at first forward, and then backward towards the posterolateral angles of the cheeks, but disappearing at the shallow marginal furrow' (1899, p. 354, transl.),

and he interpreted them as vestiges of the anterior branch of the suture. Kiær also describes and figures lines in the same position in *Kjerulfia lata* Kiær ¹ and in *Holmia kjerulfi*, and accepts them as the sutures, comparing their 'remarkable course' with what 'is also seen to some extent... in *Paradoxides rugulosus*'. Ulrich (1922, p. 205) voices the general opinion (expressed or implied) that the dorsal facial sutures are Opisthoparian in symphysis. Only Walcott and Swinnerton range themselves on the other side. ³

Significance of the Position and Condition of the Anterior Branch of the Suture. (Pl. XV, figs. 5 & 5 a, and description, pp. 319-20.)

Both Moberg and Kiær regard the genal spines as homologous with those of *Paradoxides*, that is, as parial spines. If, however, it be accepted that the genal spines of Mesonacids are procranidials, the backward course of the suture is inevitable, for these must terminate behind (and so within) the procranidial spines. An exactly similar course of the anterior branch of the suture is visible in Walcott's published photographs of *Olenellus gilberti*, and *Callavia crosbyi*, and can be seen in the Shropshire species—*C. callavei* Lapworth and *C. cobboldi* Raw MS. In this genus it can be traced farther back, reaching the marginal furrow immediately in front of the genal angle.

The identification of the genal spine with the procranidials also furnishes a complete explanation of the existence of the ventral suture, a unique character of this family. Wherever the structure is clear (for instance, in *Holmia*, *Callavia*, *Kjerulfia*) the hypostomial suture is absent as in *Paradoxides*, the hypostome being continuous in front with the doublure, which Moberg called the 'hypostome attachment'. In *Paradoxides*, the portion of doublure

¹ Kiær, 1916, p. 76.

Raymond, 1917, p. 206, was misled by a faked photograph supplied by me (Walcott, 1910; p. 418 & pl. xlii, fig. 1) into identifying a crack across the specimen as the anterior branch of the suture.

5 Ibid. pl. xxviii, fig. 1.

Walcott, 1910, pl. xii, ng. 1.

Holm, 1887, pp. 506-507 & pl. xv, figs. 13 & 14; Kiær, 1916, pp. 62 & 77;

Walcott, 1910, pl. xxxiv, figs. 5, 6, & 7.

to which the hypostome is attached is short, closely comparable with, and clearly representing, the so-called epistome or rostrum of other genera, and it is bounded at its ends by the 'connecting' sutures, which continue across the doublure the anterior branches of the dorsal sutures. 1 On the other hand, in these Mesonacid genera this 'hypostome attachment' is very long, extending under the posterolateral angles of the shield. Accordingly, whereas in Paradoxides the marginal suture is short, in these Mesonacids it is very long, serving to bound this plate throughout its length from one genal spine to the other. The same relation probably obtains in the other Mesonacids: in Pædumias this semiannular plate is apparently very narrow, as is also the connexion with the hypostome; but this is again without suture.2 Though so different in their extent we can correlate exactly the long hypostome attachment of the Mesonacidæ with the short epistome of Paradoxides, as is done by Ulrich (1922, p. 205); and we can further directly connect their difference with the difference in the position of the procranidial spines. Kiær discusses these relationships, but, being apparently unaware of the existence of the connecting sutures across the doublure in Paradoxides (the existence of which is indicated by Barrande, Angelin, Grönwald, and others),3 he concludes that the epistome

' originally had a form resembling that of Mesonacidæ, but the sutures have grown together completely with the doublure.' (1916, p. 82.)

As to the form of the epistome in Mesonacidæ, he concludes that

'it is probably a primitive state, and [it] gives evidence for the supposition that it represents a special anterior segment of the cranidium, which segment in the course of further development has either fused with the doublure. or been reduced to varying degrees.' (1916, p. 83.)

While agreeing that the epistome probably represents an anterior segment, I cannot accept this conclusion, but regard the condition in Paradoxides (except for the ankylosis at the hypostomial suture) as the primitive form; from which condition the Mesonacidæ have diverged, through the revolution of the procranidial spines from their primitive anterolateral position to a posterolateral position, to take up the function of genal spines. The fact that the family is limited to the Lower Cambrian rocks furnishes no reason for assigning to them a primitive character in this respect, for they constitute only a fraction of the Trilobite fauna, the rest of which are typical 'Opisthoparia' with some Microdiscus and Agnostus species. On the contrary, if the claims here made be accepted, the Mesonacidæ will rank in this respect as highly specialized.

¹ Barrande, 1852, pl. x, fig. 23 & pl. xli, fig. 13; see above, p. 279, footnote.

Walcott, 1910, p. 420 & pl. xxxiv, figs. 5, 6, 7.
 Barrande, 1852, pl. xxvi, fig. 3 & pl. xii, fig. 13.

The revolution of the procranidial spines involved:

- (1) the crowding of the loci of the three pairs of head-spines on the posterior border of the cheeks;
- (2) the stretching-out of the primitive anterior border with its marginal suture, so as to form the whole semicircular margin of the head-shield with its submarginal suture;
- (3) the revolution of the anterior branches of the sutures, so as to cut the posterior margin within the procranidial spines;
- (4) the revolution also of the continuation of these sutures across the doublure, the so-called 'connecting sutures'; causing
- (5) the extension of the epistome, bounded by the marginal and connecting sutures, into the semiannular 'hypostome attachment', bounded by the submarginal suture.

These changes effected as their natural consequence the supplanting of the dorsal facial sutures as the ecdysial line by the marginal and connecting sutures; for the new course of the facial suture (both anterior and posterior branches now cutting the back of the shield) would not materially assist the liberation of the cephalon in ecdysis (though it might well have assisted the liberation of the eye); while the concomitant extension of the marginal suture furnished a line of fission in a position the most effective for the purpose. Consequently, the cephalon ceased to be broken at the dorsal sutures during ecdysis, and the free cheek came to be ankylosed to the fixed cheek along this line. Thus the unique features of the Mesonacide, namely, the absence of dorsal facial sutures and the presence of an extended submarginal suture, receive, I think, a reasonably complete explanation.

But, not only have the courses of the sutures been matter for controversy, this has also been the case in regard to their significance. Ford, and Walcott at first, regarded the sutures as having been secondarily lost. Beecher also claimed the existence in the family of 'real sutures in a condition of symphysis', and this (with more reason) was the opinion of Moberg and Kiær. Walcott, however, by 1910 had reached the conclusion that dorsal sutures had not yet been evolved in this family, but were destined to appear in the Paradoxidie and Redlichia, which he regarded as their descendants. Swinnerton in 1915 also adopted the same view, deriving from the Mesonacidæ the families Remopleuridæ, Paradoxidæ, and Zacanthoidæ. My opinion, expressed above, definitely takes a side in this controversy. If it is upheld, the dorsal facial sutures in this family are vestigial and in a condition of symphysis, as is also the hypostomial suture; and the Mesonacid head could not possibly be ancestral to that of the later families mentioned, being highly specialized in a different direction.

¹ Beecher, 1897, p; 191.

XII. SUMMARY OF THE ONTOGENY AND STRUCTURE OF THE MESONACIDÆ, TOGETHER WITH THEIR PHYLOGENY.

The conclusions suggested by the ontogenies of Mesonacids are, we see, quite strongly supported by the structure of the head, and

may be briefly summarized.

In the absence of facial sutures we can seldom recognize in a single individual the loci of all three pairs of head-spines. All are, however, characteristic of Olenelloides and the larva of Olenellus gilberti, and can be recognized in a larval stage of Pædumias. From the ontogeny of this and of Elliptocephala, we conclude that in these genera the procranidial spines have migrated to the genal angles, to function as the genal spines; and so, that the loci of all three pairs are crowded on the posterior We need not be surprised, under such border of the cheeks. conditions, if one or other pair is suppressed so as to drop out of the ontogeny; and, although it is impossible as yet in most genera to prove by ontogeny that the genal spines are the anterior of three pairs, the evident unity of the family in regard to the sutures, namely, the lack of facial sutures, the courses of their vestiges, the semicircular course of the submarginal suture, all of which obtain equally in those genera (Callavia, Holmia, Kjerulfia), in which never more than two pairs of spines are seen, as in those where three pairs appear, make it appear probable that in all cases the genal spines in this family are morphologically the same, and so are procranidial spines.

That the unseen third pair of spines are sometimes coalesced with one of the other pairs is suggested by the observations of Ford on *Elliptocephala* and my own on the Alabama *Pædumias*. In both of these the metacranidial and the parial coalesce to form the intergenal spine. In *Holmia* and its allies, on the other hand, it appears more probable that the parial and procranidial are coalesced in the genal spine (Pl. XV, fig. 5, AB). Such coalescence of spines could not take place, either in the ontogeny or in the phylogeny, until after the ankylosis along the facial suture.

But if it be characteristic of the family that the loci of the three pairs are crowded on the posterior border, what significance must we attach to the condition in Olenelloides, in the aberrant forms of Olenellus fremonti, and in the species Wanneria halli? In each of these forms we note Mesonacid features combined with the presence of a pair of anterior cheek-spines. Perhaps the most plausible interpretation is that they are reversions. The reversions as usual would be incomplete, failing to restore the primitive facial sutures.

Taking the most complete development, namely that of *Pædumias*, as perhaps typical of the family, or at least a specialized branch of it, we may distinguish the following successive stages, several of which can already be recognized in other forms.

Stages in the Ontogeny of Olenellus.

Stage 1.—The Protaspis. Cephalon only, with metacranidial spines alone, the other pairs of spines possibly suppressed. (Closely approaches a larva attributed above to *Paradoxides rugulosus*.)

Stage 2.—Early Meraspid Stage. Metacranidials still dominant, but the parials now present at the posterolateral angles;

procranidials perhaps suppressed.

Stage 3.—Later Meraspid Stage. Parial spines now dominant, metacranidials reduced, procranidials now present at the posterolateral angles. Thorax narrow, with the pleuræ of the third segment extended into spines. (This stage is the nearest approach to the Heptacicephalic Stage of Leptoplastus salteri.)

[A generalized Mesonacid Stage might be expected at the first dominance of the programidial spines, but has not been recognized

in Pædumias.

Stage 4.— $\vec{P} x dumias$ Stage. Procranidial spines now dominant, parials reduced, metacranidials aborted. Thorax wider; segment 15 and its dorsal spine have appeared; behind which three (or six) segments are added in front of the anal segment. Head and thorax continue to widen, while the parial spines dwindle to disappearance.

Assuming that this development is applicable to Olenellus

thompsoni, we have a further, highest, stage—

Stage 5.—Olenellus Stage. The Rædumias segments behind the fifteenth disappear, leaving the body terminated actually (though not morphologically) by the great dorsal spine. This stage is highly reminiscent of Limulus.

A noteworthy feature in the ontogeny of Mesonacids, where not curtailed, would seem to be the succession in dominance of the three pairs of head-spines. First, the metacranidial are dominant; later, these are superseded by the parial; and these in turn by the programidial. Each of these pairs in the same individual may in turn come to occupy the posterolateral angles of the cephalon, and to constitute the genal spines. The individual Pædumias, indeed. to a great extent exhibits in turn the different types of head-shield that are met with in the adult stages of the Trilobites reviewed in this paper; and it recalls, say, Paradoxides and Ctenocephalus, where two different types of head-shield are successively assumed. These different types of cephalon are distinguished by the dispositions of the free and fixed cheeks with reference to the genal spines. Here, however, dorsal sutures are lacking, and so also free cheeks; but, apart from this, the early stages (1-2 above) with the metacranidials as genal spines suggest the 'Proparia', and the middle stage (3) with the parials as genal spines suggests the 'Opisthoparia'. The later stages (4 and 5) with the procranidials as genal spines are adult Mesonacids, and possess a previously unrecognized type of cephalon, claimed as yet only for this family. For these three types of cephalon I propose below the terms

proparial, mesoparial (= opisthoparial), and metaparial respectively. We can therefore recognize as fundamental in the ontogeny of Olenellus thompsoni:

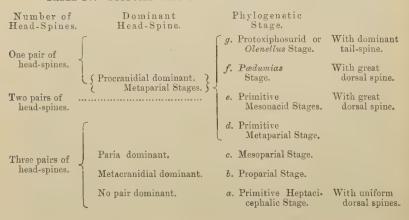
iv.	the Metaparial Protoxiphosurid, or Olenellus Stage	5 above.
iii.	the Metaparial Pædumias Stage	4 above.
ii.	the Mesoparial (modified) Stage	3 above.
i.	the Proparial (modified) Stage	1 & 2 above.

But the lack of facial sutures is a natural consequence of the adoption of the metaparial plan of cephalon, and hence these stages can be accepted as representing so many stages in the phylogeny; for, in the ancestry, the ankylosis along the suture could not occur before the Metaparial Stage had been established. The existence of Proparial and Mesoparial Stages both in ontogeny and in phylogeny depends, therefore, on the dominance of one or another pair of spines. In the Mesoparial Stage of the ontogenv both the other pairs of spines are present as well as the parials, much as a second pair of spines is present in Zacanthoides, Holmia, etc. It is, indeed, improbable that in the phylogeny the spines that were not dominant were ever lost before the Metaparial Stage. If so, the earlier phylogenetic stages, to which the ontogeny points, are so many Heptacicephalic Stages, and point back to the same generalized ancestor common to the other Trilobites which we have reviewed. Also, both the range of character among adult Mesonacids and the ontogeny of the various forms point to the existence of a phylogenetic stage with two pairs of spines, between those with three and those with one.

On these considerations we can distinguish in the phylogeny of Olenellus a number of successive stages, as in the appended

table:-

TABLE IV .- SUPPOSED STAGES IN THE PHYLOGENY OF Olenellus.



Paradoxides, too, has numerous points of agreement with the Mesonacide: namely, the similar glabella; the long crescentic eyes; the very similar hypostome; the lack of hypostomial suture; the similarly furrowed falcate pleure; the similar body-form; the large size; and the near geological horizon. And, when we add to these similarities in the adult, the passage of both through a Proparial Stage of development (p. 276) to a Mesoparial Stage, in which the adult Paradoxides finds itself, it seems probable that these two families had a common phylogeny up to a primitive Mesoparial Stage far back in pre-Cambrian time; and that this common Mesoparial ancestor had a wide anterior brim to the cephalon is indicated by the occurrence of this feature in the ontogenies of both families.

XIII. CONCLUSIONS.

The ontogeny of Leptoplastus salteri sheds much light, not only on the ontogeny of numerous other Trilobites, but also on their structure, relationships, and phylogeny: it will be found besides to have an important bearing on the phylogeny of other Arthropods.

Summaries of the major sections of this paper have already been given, and to these the reader is referred for the more detailed conclusions, namely:—

The Ontogeny of Deptopulatus suitert	pp. 242-41.
The Ontogenies of other Olenidæ, and of Ptycho-	
paridæ and Conocoryphidæ	pp. 265–66.
The Ontogenies of Paradoxidæ	pp. 275–79.
The Ontogeny, Structure, and Phylogeny of the	
Mesonacidæ	pp. 306-309.
The shorter sections, not summarized, are	
The Phylogeny of Leptoplastus salteri	рр. 248-57.
The Ontogeny of Dalmanitina socialis, and its	
Comparison with Paradoxides	pp. 280-85.
The Mutual Relations of some other 'Proparia'	
and 'Opisthoparia'	pp. 285–86.

The Ontogony of Lenton lastue calteri

The wider conclusions that follow from the considerations put forward will now be indicated.

The Common Ancestor of the Trilobites.

The various Trilobites which have here come under review, belonging to the Opisthoparia and Proparia of Beecher, or the Proparia, Opisthoparia, and Protoparia of Swinnerton, have much in common in their ontogenies, although they are characterized by three different types of head.

The study of the ontogenies helps to indicate the nature of the differences between these types, and leads to definite conclusions as to which characters are primitive, furnishing indeed the

characters of the common ancestor.

These primitive characters are:—

(1) segments numerous;

(2) trilobation pronounced, the body being very strongly divided into axial and pleural lobes;

(3) pleural lobes at least as narrow as the axial;

(4) proportionate sagittal length of each segment greater than that of later Trilobites;

(5) all normal segments bearing a median spine;

(6) pleuræ of post-cephalic segments truncated at their ends by relatively long, backwardly-directed spines;
(7) cephalon much longer for its width than in the later Trilobites, the

cheeks being relatively narrow, and the free cheeks especially so;

(8) axial lobe of cephalon composed of segments similar to those of the thorax (4 above);

(9) cephalon bearing seven peripheral spines (Heptacicephalic), one pair (the parial) being borne on the free cheek, and issuing from the mid-length of the shield, another pair (the procranidial) at the anterolateral angles of the cranidium, and a third pair (the metacranidial) at the posterolateral angles of the same, the seventh being the occipital spine;

(10) eyes very long, forming the inner boundary of the free cheek, joined by an ocular ridge to the anterior glabellar lobe, and extending

backwards to near the metacranidial spines;

(11) cephalon bearing ventrally a hypostome, and a rostral plate or epistome between the procranidial spines, this epistome being bounded by the anteromarginal suture in front, the hypostomial suture behind, and the connecting sutures at its ends, between it and the doublure of the free cheeks.

The primitive form combining these and other characters may be designated the Heptacicephalic ancestor.

The Primitive Nature of Trilobite Features.

These ontogenies lead to the conclusion that the free cheeks, the compound eyes, the dorsal sutures past these, and the abovementioned head-spines are all constant morphological entities, having definite mutual relations; and that they were primitive within the Trilobite class. There is no sufficient evidence of a stage before the formation of a facial suture (Protoparial Stage of Swinnerton). But the primitive free cheek may cease to be free (Mesonacidæ); or it may become ankylosed with the epistome (Phacopidæ), or extend to the middle line at its expense (Asaphidæ, Olenidæ). And, as the term free cheeks is used in these different cases for parts which are not strictly homologous, I suggest for this primitive morphologue the term pareïa, the source of Beecher's ordinal names—Proparia, etc.

The three pairs of head-spines have definite morphological positions, the programidial and metagranidial respectively forming the anterolateral and posterolateral angles of the primitive cranidium, and adjoining respectively the anterior and posterior branches of

the facial suture; while the parial is borne by the pareïa.

The Three Primitive Plans of Trilobite Cephala.

The three pairs of spines of the ancestor are the origins of the genal or cheek-spines of Trilobites; and the type of cephalon differs according as one or another pair survive to form the genal spines. Persistence of the metacranidials to constitute the genal spines is the case with the Proparia of Beecher; though he made this include also the Calymenidæ. On the other hand, the persistence of the parial spines as genal spines holds good in the majority of Trilobite families: that is, in the typical members of that writer's Opisthoparia. Of this type of structure he supposed that the Mesonacids also were specialized examples. But I have claimed that this family have a quite different plan of cephalon, characterized by the persistence of the procranidial spines, rotated to the rear, to function as genal spines.

Besides the structures of Beecher's Hypoparia, with which we are not here concerned, there are, then, three fundamental types

of cephalic structure:—

in I, the pareïa and its margin lie wholly in front of the genal spine, which is, in this case, the metacranidial;

in II, the pareïa includes the genal spine, so that its margin

extends to either side of this spine, which is here the parial;

in III, the pareïa and its margin morphologically lie wholly behind the genal spine, which is here the procranidial.

Beecher recognized the first two of these three types, and called them Proparial and Opisthoparial respectively; but Type III is in structure the true Opisthoparian. The structure of Beecher's Opisthoparia or Type II is intermediate between Types I and III in two respects: namely, in that the parial spine, the central of the three pairs of cheek-spines, is the genal spine; and in that the pareïa holds an intermediate position between those characterizing Types I & III.

It would be inadvisable to alter the significance of Beecher's

term, and I propose for these three types the terms:—

I, Proparial type, identical with that of Beecher's Proparia; II, Mesoparial type, to replace Beecher's term 'Opisthoparial', characteristic of his Opisthoparia, less the Mesonacide; III, Metaparial type, for this newly-claimed structure of the

Mesonacidæ.

Trilobites exhibiting these different types of cheek-plan may be designated Proparians, Mesoparians, and Metaparians respectively. The new terms are not proposed as names for ordinal divisions of Trilobites to replace Beecher's Opisthoparia, for I believe that the phylogeny of Trilobites runs along quite different lines.

With the entire loss of the genal spines which characterizes the late members of several Trilobite stems belonging to Types I & II, the distinctions between these types are somewhat diminished, as, for instance, in the Calymenidæ; but the position of the suturelines is usually sufficient to discriminate between them.

Trilobites exhibit in general a semicircular head-shield with

spines at the posterolateral angles, but these spines, it is claimed, may be: the primitively posterolateral spines, that is, the metacranidials, as in the Proparians; or the parials, revolved more or less to the rear, as in the Mesoparians; or, lastly, the genal spine may be the procranidial, revolved from an anterolateral to a posterolateral position, carrying before them the anterior branches of the suture, and stretching out to the genal angle the ventral epistome and the marginal suture which bounds it in front, as in the Metaparians, represented by the Mesonacidæ. Here, owing to the anterior branches of the facial sutures being revolved to the rear, coincidently with the extension of the anteromarginal suture to the genal angles, this marginal suture became sufficient for ecdysis at the same time that the dorsal facial suture became ineffective. In consequence, ankylosis subsequently occurred along the lines of the dorsal facial sutures, and the absence of these is thus a secondary, not a primary, feature in these Trilobites. But, quite apart from this secondary change, the Metaparial plan of cephalon is, by the extensive revolution of its spines, farthest removed from the primitive Heptacicephalic condition, and so most specialized; while the Proparial cephalon in the same character is the most primitive.

Changes widely different from those which have evolved the Mesonacidæ have affected the progranidial spines and the connecting sutures in some other trilobites. In Asaphida and Olenida, concurrently with the loss of the programidial spines, their loci have moved in towards the glabella; and the connecting sutures in the same process appear to have been carried towards one another until they coalesced in the mid-line. (See also below.)

All three types of head-plan are represented in the Cambrian System, but only the Proparial and Mesoparial are recorded from higher systems. On the other hand, it is only the Metaparial among known Trilobite families that can be claimed to have any recent descendants.

Relation of Ontogeny to Phylogeny in the Trilobites reviewed.

In Leptoplastus and its relations (the other Olenidæ abruptæ, and inermes) as well as several other Mesoparial Trilobites, although it is the parials that survive as the genal spines, there has been only a moderate rotation of these to the rear. Indeed, in Ctenopyge and Spherophthalmus there has often been rotation round to the front, in contrast with what usually obtains in Mesoparial Trilobites.

Of L. salteri we do not know as yet the protaspis stages; but, in its known development, it exhibits four stages: (1) a Heptacicephalic Stage, reminiscent of Olenelloides armatus and of the larva of Olenellus gilberti; (2) a Ctenopleural or generalized Ctenopyge Stage; (3) an Autogeneric or primitive Leptoplastus Stage; and (4) the Autospecific Stage of the adult. The presence here of so perfect a Heptacicephalic Stage interpreted as primitive, and the direct development into the succeeding stages with Mesoparial head-plan may perhaps be connected with the more primitive position of the parial spine in the group to which

it belongs.

The stages of development of L. salteri are interpreted as being to no small extent a recapitulation of its ancestry. And this is believed to be the case also in the other trilobites reviewed. But, in all cases, particular advanced characters are already present by tachygenesis in the early stages; while, in some cases, there are also present in these stages features which comparisons show to be especially larval characters. As advanced characters present by tachygenesis we may interpret the concentrated eye, the absence of a fourth glabellar furrow, and the pygidium (of many segments) of the Leptoplastus larva, the absence of the facial sutures in the Mesonacid larva, and the absence of the procranidial spines in the Paradoxides larva. As specialized larval characters we may note the glabellar swelling of the Hydrocephalus type of Paradoxides larva, and the positions of the eyes in the larvæ of Leptoplastus and of Dalmanitina.

While in L. salteri there seems to be direct development from the Heptacicephalic Stage into stages with a Mesoparial head-plan, on the other hand, in the ontogeny of the Paradoxidæ, Ptychoparide, and Conocoryphide—other Mesoparians, the metacranidial spines seem at first to be dominant, and to be afterwards superseded in dominance by the parial spines. These in their ontogeny seem to pass from a stage with Proparial head-plan to one with Mesoparial. This is interpreted as applying also to their phylo-The procranidial spines have not been observed in these families, so that, if a true Heptacicephalic Stage persisted in their ontogeny, it may have been embryonic.

Furthermore, in *Paradoxides* two different types of development characterize respectively the primitive long-eyed forms, and some of the advanced short-eyed forms. The long-eyed forms, which besides being primitive as adults exhibit also the more primitive larvæ, are believed more nearly to recapitulate their ancestry; while Barrande's 'Hydrocephali', here claimed to be the larvæ of short-eved forms, are interpreted as a specialized larval stage limited to these forms, and far removed in the glabella from the

corresponding phylogenetic stage.

The young larva of the Proparial Dalmanitina socialis is very near to the more primitive Paradoxides larva, except in its eyes and facial suture, in which respects it is regarded as a specialized larva. Here only the metacranidials appear in the ontogeny, and

it is thus Proparial throughout the development.

In the ontogeny of Mesonacidae again, the protaspis of several forms closely approaches the same Paradoxides larva, and the metacranidial spines are at first dominant. These are succeeded in dominance by the parial, and these again by the procranidial spines. Thus they are successively Proparial, Mesoparial, and Metaparial in their ontogeny; which is accepted as evidence of corresponding stages in their phylogeny, part of which they had

in common with the Paradoxidæ.

But great variation obtains within the Mesonacidæ in development, as well as in adult characters; and, as a result of the crowding of the spines on the posterior border, characteristic at least of later stages of development, and consequent upon the ankylosis along the branches of the facial suture, there is a marked tendency to a coalescence of spines. Thus the genal

the coalesced procranidial and parial spines.

Apparent Course of Evolution of Head-Plan.

spines of Holmia, Callavia, and Kjerulfia are believed to be

In the Trilobites, to judge from the form of the head, there seems to have been a marked tendency towards a semicircular or rather a tetartospherical head-shield; and, although the evidence summarized above is as yet slight, it appears to me sufficient for the conclusion that in the past history of the forms, as well as in their development, the spines primitively nearest to what became the horns of the head-shield, namely, the metacranidial spines, first assumed dominance (primitive Proparians). Some of these originated the known Proparial Trilobites, by the abortion of the other two pairs of head-spines. But in others of them the parial spines, which still persisted, later migrated rearwards and assumed dominance (primitive Mesoparians). Some of these latter originated the known Mesoparial Trilobites (Beecher's Opisthoparia minus the Mesonacidæ) by the abortion of the procranidial spines, and in nearly all cases the metacranidial also. But in others of the primitive Mesoparians, the programidial spines, which still persisted, later migrated rearwards and assumed dominance (primitive Metaparians). These evolved into the Mesonacidæ by ankylosis along the now useless dorsal facial sutures, and by coalescence or suppression of spines.

Ontogeny: a Valuable Test of Affinity.

The early stages of development with certain exceptions (larval specializations) are regarded by me as a valuable test of affinity, which is especially indicated by the form of the glabella. Thus many different members of the Olenidæ, which Beecher divided between the Oleninæ and Oryctocephalinæ, are closely similar in early stages, having a glabella of even width throughout, with regular segmentation. Triarthrus is, in this way, shown to belong to the Olenidæ.

On the other hand, the Ptychoparidæ have a different larval form, justifying their separation from the Olenidæ in which Beecher placed them, and their association in the family Ptychoparidæ as laid down by Matthew.

But the same characters are present also in the larvæ of Conocoryphidæ, an apparently blind family. Their ontogenies thus indicate a very close relationship between the Conocoryphidæ and the Ptychoparidæ, the conclusion being inevitable that the

former are but specialized scions of the latter. A marked feature of the two families, as also of the related Calymenidæ, is a later narrowing and shortening of the frontal lobe of the glabella. The last-named family was included by Beecher in his Proparia; but Pompeckj has claimed its relationship with the Ptychoparidæ. There are, however, other unquestionable Proparians (the Menomonidæ) described by Walcott from the Middle Cambrian which are above claimed, on the basis of their glabellar forms, to be closely related to these families: namely, Menomonia, Dresbachia, and Norwoodia to the Ptychoparidæ, and Millardia to the Conocoryphidæ.

The close resemblances between these four families force the conclusion that they form a single natural order of Trilobites,

although including such variety of head-structure.

Close comparisons again can be instituted, not only between the adult glabellas of Dalmanites, Paradoxides, and several Mesonacids (for instance, Holmia, Wanneria, Olenellus), but also between their larvæ. The characters in which they agree are, it is true, largely primitive; but, taken together, they suggest, as I think, a closer relationship between members of these three families (Phacopidæ, Paradoxidæ, Mesonacidæ), with respectively Proparial, Mesoparial, and Metaparial head-plan, than any of them can claim with other families.

Principles of a Natural Classification of Trilobites.

These considerations suggest a different principle of classification from that adopted by Beecher in instituting his orders. Beecher made the head-plans, as he interpreted them, the fundamental divergence within the class; and divided the Trilobites into three orders-Hypoparia, Opisthoparia, and Proparia. On the other hand, the form of the glabella has been universally recognized as, in general, a valuable index of affinity; but, except by Chapman, it has not been made the chief basis of classification, and extended to Trilobites of different head-plans. If, however, the essential distinctions between the three fundamental types of head-plan have above been rightly determined, and if the order of development of the different features in the ontogeny has been rightly read, we should be in a position to judge which of two kinds of divergence is the more primitive: namely, divergence by head-plan, or by glabella—that is, by specialization of particular primitive headspines, a specialization affecting the pleural regions of the head, or by specialization of the glabellar segments, covering the most highly organized part of the body. The post-cephalic pleural regions are the scene of very varied specializations in Trilobites, and of the evolution of blunt-ended from pointed pleuræ, a feature common to several families, and well illustrated by the range between Ctenopyge and Acerocare in the Olenidæ; but these belong more especially to the later history of the class. The glabella, on the other hand, more consistently maintains its character throughout the history of each family, though it, like the pleure, also exhibits parallel evolution in several families in the direction of smoothness.

But a natural classification, if such were attainable, is simply one that expresses correctly the history of the divergences within The main divisions should express an early divergence, and the successive subdivisions the later divergences in order. The different types of head-plan may be very remarkable, even more remarkable than Beecher supposed, but are they fundamental? Did the divergence into different types of head-plan antedate other divergences? We must appeal to ontogeny to supply the answer. Already, in the earliest stages of development one can recognize different types of glabella; but the larvæ in this stage are alike Proparial, or else more primitive—Heptacicephalic; and the change to the Mesoparian or Metaparian is a later development. It is thus natural to infer that the divergence in glabellar form and what it implies began very early, much earlier than the evolution of different types of head-plan; and that it is for this reason that its representation in the ontogeny is pushed back into the embryo. This, on further consideration, appears not unreasonable. The changes in glabellar form must be correlated with changes in the characters and distributions of the limbs belonging to its segments ventrally; and changes in these would be likely to follow the earliest divergence into different modes of life. I conclude, then, from the facts, that in the pre-Cambrian history of the Trilobites there had been a fundamental divergence in glabellar form, doubtless correlated more especially with divergence in the cephalic limbs, and subsequent divergences in head-plan.

The further conclusion naturally follows that neither Proparial, nor Mesoparial, nor Metaparial Trilobites necessarily form natural orders, any more than do the members of Beecher's 'Hypoparia', to which objection has already been raised by many. The same phyletic division of Trilobites may in different families exhibit all three types of head-structure, because it might subsequently in different cases adopt the several modes of life to which the different

head-plans were related.

To Mr. E. S. Cobbold, F.G.S., who very kindly read through the original manuscript and furnished many valuable suggestions, I gladly acknowledge my indebtedness, and tender my warmest thanks.

XIV. References.

Angelin, N. P. Barrande, J.	1854. 1852.	The state of the state of the bolletine vol. 1
BARRANDE, J.	1872.	texte & planches. 'Système Silurien du Centre de la Bohême' vol. i, Supplément—texte & planches.
BEECHER, C. E.	1895.	The Larval Stages of Trilobites' American Geologist, vol. xvi, p. 166.
Brecher, C. E.	1897.	'Outline of a Natural Classification of the Trilobites' Amer. Journ. Sci. ser. 4, vol. iii. p. 89.

Part =] 2221101	222020	5 SALIENT AND OTHER TRILOBILES. OT
BEECHER, C. E.	1900.	'Trilobita': in Zittel's 'Text-Book of Palæontology'
BERGERON, J.	1899.	ed. Eastman, vol. i, p. 607. 'Étude de quelques Trilobites de Chine' Bull. Soc.
BURLING, L. D.	1916.	Géol. France, ser. 3, vol. xxvii, p. 499. 'Pædumias & the Mesonacidæ' Ottawa Naturalist,
BERNARD, H. M.	1894.	vol. xxx, p. 53. 'The Systematic Position of the Trilobites' Q.J.G.S.
CALLAWAY, C.	1874.	vol. I, p. 411. On a Tremadoc Area near the Wrekin in South Shropshire, &c. Q. J. G. S. vol. xxx, p. 196.
CALLAWAY, C.	1877.	On a New Area of Opper Cambrian Rocks in South
CHAPMAN, E. J.	1889.	Shropshire, &c.' Q. J. G. S. vol. xxxiii, p. 652. 'Some Remarks on the Classification of the Trilobites, as influenced by Stratigraphical Relations, &c.'
Dollo, L. 1909	(1910).	as influenced by Stratigraphical Relations, &c.' Trans. Roy. Soc. Can. sec. iv, p. 113. 'La Paléontologie Ethologique' Bull. Soc. Belge Géol.
FEARNSIDES, W. G.	1905.	Mém. vol. xxiii, p. 377. 'On the Geology of Arenig Fawr & Moel Llyfnant' Q. J. G. S. vol. lxi, p. 608.
FORD, S. W.	1877.	'On some Embryonic Forms of Trilobites, &c.' Amer.
FORD, S. W.	1878.	Journ. Sci. ser. 3, vol. xiii, p. 265. 'Note on the Development of Olenellus asaphoides' Amer Journ Sci. ser. 2, vol. vol. 120.
FORD, S. W.	1881.	Amer. Journ. Sci. ser. 3, vol. xv, p. 129. 'On Additional Embryonic Forms of Trilobites, &c.' Amer. Journ. Sci. ser. 3, vol. xxii, p. 250.
GRÖNWALL, K. A.	1902.	'Bornholms Paradoxideslag og deres Fauna' Dan- marks Geol. Undersög. ser. 2, No. 13.
GUERICH, G.	1907.	'Versuch einer Neueinteilung der Trilobiten' Centralbl. f. Min. p. 129.
HŒRNES, R.	1880.	'Die Trilobitengattungen: Phacons & Dalmanites'
HOLM, G.	1887.	Jahrb. K.K. Geol. Reichsanst. vol. xxx, p. 651. 'Om Olenellus kjerulfii Linrs.' Geol. Fören. Stockholm Förh. vol. ix, p. 493.
HOLTEDARL, O.	1910.	'Ueber einige Norwegischen Oleniden' Norsk. geol. Tidsskr. vol. ii, no. 2.
ILLING, V. C.	1915.	The Paradoxidian Fauna of a part of the Stocking-
Jæckel, O.	1909.	ford Shales' Q. J. G. S. vol. lxxi, p. 386. 'Ueber die Agnostiden' Zeitschr. Deutsch. Geol. Gesellsch. vol. lxi, p. 380.
KIÆR, J.	1916.	'The Lower Cambrian Holmia Fauna at Tomten in
LAKE, P.	1908.	Norway' Christiania [Oslo]. 'British Cambrian Trilobites' pt. iii, Monogr. Palæontogr. Soc.
LAKE, P.	1913.	'British Cambrian Trilobites' pt. iv, Monogr. Palæontogr. Soc. 1912.
LAKE, P.	1919.	'British Cambrian Trilobites' pt. v, Monogr, Palæontogr, Soc. 1917.
LAPWORTH, C.	1891.	'On Otenellus Callavei & its Geological Relationships' Geol. Mag. vol. xxviii, p. 529.
Linnarsson, G.	1877.	'Om Faunan i Lagren med Paradoxides ælandicus' Geol. Fören. Stockholm Förh. vol. iii, p. 352.
Linnarsson, G.	1880.	'Om Försteningarne i de Svenska Lagren med Peltura & Sphærophthalmus' Geol. Fören. Stockholm Förh.
MATTHEW, G. F.	1882.	vol. v, p. 132. 'Illustrations of the Fauna of the St. John Group: No. 1. The Paradoxides' Trans. Roy. Soc. Can.
MATTHEW, G. F.	1884 A	sec. iv. p. 87. Do. 'On the Conocoryphea, with further Remarks on Paradoxides' Trans. Roy. Soc. Can. sec. iv, p. 99.
MATTHEW, G. F.	1884в	. 'An Outline of Recent Discoveries in the St. John Group' Bull. Nat. Hist. Soc. New Brunswick, vol. iv,
MATTHEW, G. F.	1887A	p. 97. 'Illustrations of the Fauna of the St. John Group, No. 4, Pt. ii: the Smaller Trilobites with Eyes' Trans. Roy. Soc. Can. sec. iv, p. 123.
MATTHEW, G. F.	1887 в	. 'Illustrations of the Fauna of the St. John Group, No. 4—On the Smaller-Eyed Trilobites of Division I, &c.' Canadian Rec. Sci. April 1887, p. 357.

MATTHEW, G. F.	1889.	'Sur le Développement des Premiers Trilobites' Ann.
Matthew, G. F.	1893.	Soc. R. Malac. Belg. vol. xxiii (1888) p. 351. 'Illustrations of the Fauna of the St. John Group, No. 8' Trans. Roy. Soc. Can. sec. iv, p. 85.
Moberg, J. C. & Möller, H.	1898.	'Om AcerocareZonen' Geol. Fören. Stockholm Förh. vol. xx, p. 197.
Moberg, J. C.	1898.	'Supplement till "Om AcerocareZonen" ibid. p. 314.
Moberg, J. C.	1899.	'Sveriges Älsta Kända Trilobiter' ibid. vol. xxi, p. 309.
PEACH, B. N.	1894.	'Additions to the Fauna of the Olenellus Zone of the North-West Highlands' Q. J. G. S. vol. l, p. 661.
Persson, E.	1904.	'Till Käunedomen om Oleniderna i "Zonen med Eury-
D T E	1000	Stockholm Förh. vol. xxvi, p. 507. 'Ueber Calymene Brongniart' Neues Jahrb. p. 187.
Pompecki, J. F. Raw, F.	1898. 1907.	'The Development of Olenus salteri Callaway' Rep. Brit. Assoc. p. 513.
RAYMOND, P. E.	1913.	'Trilobita': in Zittel's 'Text-Book of Palæontology,' ed. Eastman, vol. i, p. 692.
RAYMOND, P. E.	1914.	Notes on the Ontogeny of Paradoxides' Bull. Mus. Comp. Zool. vol. lviii, p. 223.
RAYMOND, P. E.	1917.	'BEECHER'S Classification of Trilobites after 20 years' Amer. Journ. Sci. ser. 4, vol. xliii, p. 196.
RAYMOND, P. E.	1920.	'The Appendages, Anatomy, & Relationships of Trilobites' Mem. Conn. Acad. Arts & Sci. vol. viii, p. 1.
REED, F. R. C.	1898.	'Blind Trilobites' Geol. Mag. vol. xxxv, p. 493.
REED, F. R. C.	1905.	'The Classification of the Phacopidæ' ibid. vol. xlii,
REED, F. R. C.	1914.	pp. 172 & 224. 'Lower Palæozoic Trilobites of Girvan' Supplement, Monogr. Palæontogr. Soc. 1913.
SALTER, J. W.	1869.	'On some Fossils from the Menevian Group' Q.J.G.S.
& HICKS, H.	1000	vol. xxv, p. 51.
STÖRMER, L.	1922.	'En Ny Bæckia-Form fra Dictyograptus Kalk paa Hadeland' Norsk, Geol. Tidsskr. vol. vi, p. 223.
SWINNERTON, H. H.	1915.	'Suggestion for a Revised Classification of Trilobites' Geol. Mag. vol. lii. p. 538.
SWINNERTON, H. H.	1919.	Geol. Mag. vol. lii, p. 538. 'The Facial Suture of the Trilobite' ibid. vol. lvi, p. 103.
Тномав, Н. Н.	1900.	p. 103. 'Fossils in the Oxford University Museum, IV: Notes on some Undescribed Trilobites' Q. J. G. S. vol. lvi, p. 616.
Ulrich, E. O.	1922.	'Ordovician "Hypoparian" Genera of Trilobites' Bull. Geol. Soc. Am. vol. xxxiii, p. 205.
WALCOTT, C. D.	1879.	'Fossils of the Utica Slate' Trans. Albany Inst. vol. x, p. 18.
WALCOTT, C. D.	1886.	'The Cambrian Faunas of America' U.S. Geol. Surv. Bull. 30.
WALCOTT, C. D.	1891.	'Fauna of the Lower Cambrian or Olenellus Zone' 10th Ann. Rep. U.S. Geol. Surv. p. 509.
Walcott, C. D.	1908.	'Cambrian Trilobites: Cambrian Geology & Palæ-
		ontology, No. 2' Smithsonian Miscell. Collect.
Walcott, C. D.	1910.	brian Geology & Palæontology, No. 6' ibid. vol. liii,
WALCOTT, C. D.	1912.	p. 229. 'The Sardinian Cambrian Genus Olenopsis in America: Cambrian Geology & Palæontology, No. 8' ibid.
Walcott, C. D.	1916.	vol. lvii, p. 237. 'Cambrian Trilobites: Cambrian Geology & Palæ- ontology III No 3' ibid vol lviv p. 157
Walcott, C. D.	1917 A.	'The Albertella Fauna in British Columbia & Montana; Cambrian Geology & Palæontology IV, No. 2'
WATCOTT C D	10177	ibid, vol. lxvii, p. 9.
WALCOTT, C. D. WALCOTT, C. D.	1917 B.	'Fauna of the Mount Whyte Formation' ibid. p. 59.
WEDEKIND, R.	1911.	'Appendages of Trilobites' ibid. p. 115. 'Klassification der Phacopiden' Zeitschr. Deutsch.
Marker C		Geol, Gesellsch, vol. 1x111, p. 317.
WESTERGARD, H. H.	1922.	'Sveriges Olenidskiffer' Sver. Geol. Undersökn, ser. Ca, No. 18.

EXPLANATION OF PLATES XV-XVIII.

PLATE XV.

Diagrammatic outlines of relatively primitive examples of different types of Trilobite cephala, showing the composition and the disposition of homologous parts.

- Fig. 1. Heptacic cephalon of Leptoplastus salteri in Degree 3, × 18, exhibiting a primitive condition in the possession of all three pairs of headspines, original. See Pl. XVI, figs. 4 & 5.
 - 2. Mesoparial cephalon of Albertella bosworthi Walcott (after Walcott) primitive in its glabellar segmentation, in its elongated eyes, and in the position of its parial spines.1

3. The Proparial Dalmanitina hausmanni Brongniart, dorsum, modi-

fied after Barrande.2

3 a. The same, ventrum, modified after Barrande.³

4. The Mesoparial Paradoxides spinosus Beeck, dorsum, after Barrande.4

4 a. The same, ventrum, original.⁵

5. The Metaparial Kjerulfia lata Kiær, dorsum, modified after Kiær, 5 α. The same, ventrum, modified after Kiær.⁷

Index to all the figures in the above Plate.

Primitive dorsum—unshaded, consisting of cranidium and pareïæ.

Primitive ventrum—shaded;—the epistome (front) by vertical lines, the cranidium doublure (rear) by vertical lines, the pareïæ doublures by horizontal lines, and the hypostome by cross-hatched lines.

Head-Spines: -A. Procranidial spines; X. loci of their bases when these spines are absent.

B. Parial spines.

C. Metacranidial spines; Z. loci of their bases when these spines are absent.

Sutures :-

HH. Hypostomial suture. XMX. Antero-marginal suture.

O₁O₂. Ocular section

O.X. Anterior branch of the dorsal facial suture.

O,Z. Posterior branch

 XX_1 . Connecting sutures. ZZ_1 . Posterior ventral sutures. Wentral extensions of the facial sutures.

The sutures are in heavy line. Where this is continuous they are operative; where broken, symphysis has occurred along them, but they are still traceable; where dotted, they are not traceable, and are hypothetical.

Notes:-The genal spines are constituted in Proparian Trilobites (fig. 3) by the metacranidial spines; in Mesoparians (figs. 2 & 4) by the parial spines; in Metaparians by the procranidial spines. In the Metaparial form selected (fig. 5) the parial spine is inferred to be coalesced with the procranidial; but, if Elliptocephala or Olenellus had been selected, the procranidial alone would have constituted the genal spine.

¹ Walcott, 1908, pl. i & 1917, A, pl. vii.

² Barrande, 1852, pl. i, fig. 1.

³ Ibid. pl. i, fig. 4.

⁴ Ibid. pl. xiii, fig. 1. ⁵ Ibid. pl. xii, fig. 13.

⁶ Kiær, 1916, p. 74, fig. 12.

⁷ Ibid. p. 77, fig. 13.

The pareïæ in fig. 4, as in many other Mesoparial and Proparial Trilobites, retain their primitive sutural boundaries.

In the Phacopidæ (fig. 3) the two pareïæ are ankylosed with the epistome, and the connecting sutures between these parts are not traceable. These three parts together here constitute the 'free cheek'.

In Metaparial Trilobites (fig. 5) each pareïa is ankylosed to the cranidium,

along both the anterior and the posterior branches of the facial suture. Only the antero-marginal and the connecting sutures remain operative, and they

replace the facial suture as the ecdysial line.

Dorso-ventral redistribution.—In fig. 3 a considerable marginal strip has been added to the dorsum from the primitive ventrum. In Metaparial Trilobites (fig. 5), on the contrary, so far as known, the great development of the anterior brim not only carries the progranidial spines to the posterolateral angles, but transfers a narrow strip of the dorsum to the ventral side, as seen in fig. 5 a.

PLATES XVI-XVIII.

Leptoplastus salteri. Photographs illustrating its development, arranged in order of size. All from the brook-section at Shineton (Shropshire). R.R. numbers refer to H.M. Geological Survey Collection; W.K.W. to the private Collection of the Rev. W. K. Wyley, M.A.; Sedgwick Mus. to the Sedgwick Museum, Cambridge.

PLATE XVI.

Fig. 1. Degree $1, \times 30$. Convex mould, poorly preserved, but practically complete. The right pareïa is present, with its parial spine arising from a little behind the mid-length of the cephalon. Compare with

fig. 5. (W.K.W. on 29 B, Ph. 1 a), pp. 230-33.

 Degree 1, x 25. Convex mould. Cranidium and thoracic segment, no pygidium. The long and narrow axial lobe shows simple segmentation, and the longest glabellar lobe is the anterior, which reaches the front of the cephalon. The procranidial and metacranidial spines are seen on both sides. The thoracic segment is slightly displaced. (R.R. 2181, Ph. 1), pp. 230-33.

3. Degree 2, × 25. Concave mould. Cranidium and thorax only. The cranidium is sharply bounded on the right by the facial suture. The progranidial and metagranidial spines are seen, the latter represented by their bases only. Note the concave terminations of the pleuræ continued into the pleural spines. This is enlarged from the negative of fig. 14. (R.R. No. ?, Ph. 2), pp. 230-34.

Figs. 4 & 5. Degree 3, × 30. Concave mould of complete individual, showing all three pairs of cephalic spines, as well as the occipital spine. The axial lobe is somewhat widened by crushing. The facial suture on the right is seen in fig. 4; one of the pleural spines of the pygidium on the left in fig. 5. Note the great length of the pleural spine of the 3rd thoracic segment. (On Sedgwick Mus. 136, Ph. 4 & 4a), рр. 230-34.

Fig. 6. Degree 3, × 30. Concave mould. Complete, except for the pareïæ. The procranidial spine on the right and the metacranidial on the left are visible. Behind the occipital spine axial spines are traceable on the segments as far as the third segment of the pygidium. Long pleural spines also are traceable on the pygidium. (On Sedgwick

Mus. 136, Ph. 5), pp. 230-34.

7. Degree 4, × 30. Concave mould. The right pareïa is missing; the left one is displaced, and its parial spine is prominent. The glabella has now withdrawn from the anterior margin, leaving a marginal rim. The bases of the metacranidials, of some posterior pleural spines, and of the occipital are seen. (On Sedgwick Mus. 136, Ph. 6), pp. 230-33, 235.

PLATE XVII.

Fig. 8. Degree 5, × 18. Concave mould. The left pareïa is displaced, and displays its curved parial spine. The left procranidial is prominent, as also the base of the right metacranidial. Several axial spines are evident on the thoracic and pygidial segments, and fine long pleural spines are traceable on the pygidium. (On Sedgwick Mus. 136, Ph. 9), pp. 235-36.

Figs. 9 & 10. Degree 5 (left) and Degree 6 (right), × 18. Concave moulds, very imperfect. The changed form of the anterior thoracic pleural spines is seen in Degree 6 on the right of the third thoracic segment. The pygidial pleural spines are seen on the left of Degree 5 and on the right of Degree 6. (On Sedgwick Mus. 136, Ph. 12 & 13),

pp. 235-36.

Fig. 11. Degree 6, × 12. Convex mould. Pareïæ wanting. The reduced procranidials are visible, especially that on the right, as a short sharp cone forming the anterolateral angle of the cranidium, but well within the marginal rim. The two metacranidials are present as short cones. The anteromarginal suture is beginning to cut the marginal rim obliquely, making this appear to narrow at each end. The glabella, which has withdrawn from the marginal rim, is disfigured by the pressure against the front of the hypostome. (On

W.K.W. 29 B, Ph. 22), pp. 236-37.

Figs. 12 & 13. Degree 7, × 6. Concave mould. The pareïæ are each bent upon the facial suture towards the main plane of the fossil, and the anteromarginal suture has consequently given way, but not so the median ventral 'connecting suture'. The projections of the pareïæ beneath the anteromarginal rim are in this way displaced forward (fig. 12). The glabella is again as in fig. 11, disfigured by the hypostome. Being an external mould, the bases of the axial spines are seen. None occur now on the pygidium. (One of Callaway's typespecimens, also on fig. 21 of Pl. XVIII; Birmingham Univ. Mus., Ph. 11 & 11 a), pp. 236–37.

Fig. 14. Degree 9, × 6. Concave mould. It lacks the pareïæ, and does not show cephalic spines. It is lit from the right bottom corner, so as to display the pygidium. The original of fig. 3 is seen on the left.

(R.R. No. ?, Ph. 18), pp. 238-39.

15. Degree 10 (?), × 6. Concave mould. Incomplete cephalon, with three thoracic segments. The cranidium, as also that of fig. 14, is bounded in front by the anteromarginal suture cutting the rim obliquely. On the right, in front of the palpebral lobe, is seen a vestige of the procranidial spine; and the right metacranidial can also be seen. These have not been observed in later stages. (R.R. No.?, Ph. 24), pp. 238-39.

16. Degree 10, × 6. Concave mould. Complete specimen somewhat shortened (telescoped) at the back of the thorax. It shows the right metacranidial and three pleural spines on the left of the pygidium.

(W.K.W. on 29 A, Ph. 25), pp. 238-39.

17. Degree 11, × 6. Concave mould. The anterior half is somewhat weathered, but the posterior half shows the pygidium and the varied form of the pleural spines on this and on the thorax. (Sedgwick Mus. 127, Ph. 17), pp. 238-39.

PLATE XVIII.

Fig. 18. Degree 12, × 6. Concave mould of small individual with displaced pareix. It shows the bases of axial spines, and the posterior pleural spines, those on the pygidium numbering one pair and a vestige of a second. (Sedgwick Mus. 136, Ph. 14), pp. 239-41.
19. Degree 12, × 3. Convex mould. The pareix are bent on the facial

19. Degree 12, × 3. Convex mould. The pareirs are bent on the lactar suture into the main plane. The pygidium shows one pair of points. (The small individual is in Degree 9.) (W.K.W. 29 B, Ph. 16.)

Fig. 20. Degree 12, × 6. The pygidium and the left pareïa are missing. The glabella and the axis of the thorax are specially widened by pressure. The right pareïa, displaced forwards and outwards, shows the facets of the eye (not traceable in the collotype), and the extension of its ventral doublure towards the median plane. (R.R. 2260, Ph. 19.)

21. Degree 12, × 3. Concave mould. Shows the bases of the axial spines, and (more perfectly than fig. 20) the range of form of the pleural spines from back to front. The pygidium still bears a pair of pleural points. (Callaway's type-specimen, Birmingham Univ.

Mus., Ph. 15.)

[Figs. 22-24 are the largest individuals, from 5 to 8 times as large as that

of fig. 21.]

Fig. 22. Degree 12 (f), × 1·20. Outer surface of the integument of the cranidium, seven thoracic segments, and pygidium. The glabella is almost smooth. The anteromarginal rim has all but disappeared. The axial lobe is crushed down, especially at the right side. The extent of the compression can be gauged in the specimen by comparison of its profile with that of the isolated segment lying on its anterior margin in front of the pygidium. The anterior segment of the latter still bears a pair of blunt teeth. (W.K.W. 25 α, Ph. 20.)

23. Degree 12?, × 1·20. Convex mould. Largest-known cephalon, with front part of the thorax. Note the glabella now concave in front, and well away from the marginal rim, which is marked by the impression of the doublure. (R.R. 2268, Ph. 21), pp. 239-41.

24. Degree 12 (f), × 1·20. Outer surface of the integument of the pygidium, and the last thoracic segment with its robust axial spine extending back nearly to the limit of the photograph. The margin of the pygidium is now entire, and markedly concave behind the axis. Beyond this concavity on each side the fracture follows the concentrically ribbed doublure. (R.R. 2234, Ph. 23), p. 241.

25. Degree 12. Mould of inner surface of right pareïa with eye, × 15. Lit from the right. The eye exhibits the very numerous facets; it would belong to an individual a little larger than that of fig. 21.

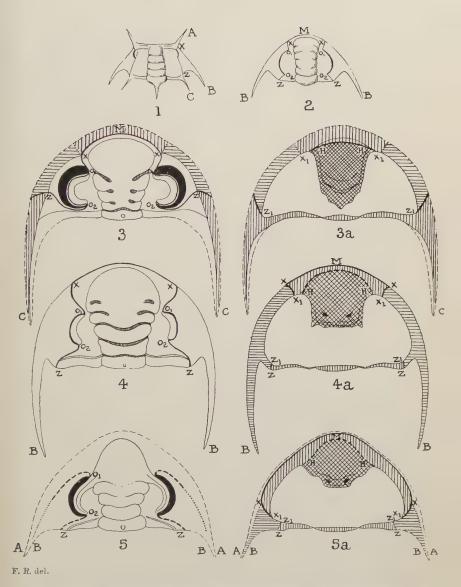
(R.R. 2188), p. 240.

26. Degree 12. Hypostome of young individual, × 15. Convex mould. (R.R. 2181), p. 240.

DISCUSSION.

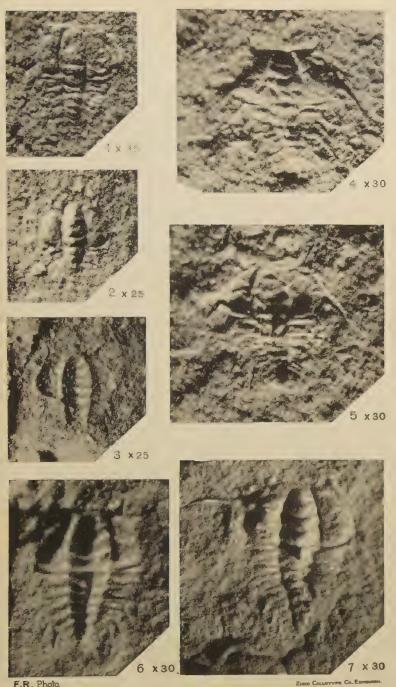
Prof. H. H. Swinnerton congratulated the Author upon finding such interesting material, and upon the careful way in which he had carried out his investigation. Referring to the more theoretical portions of the paper, he felt that the Author attached too much importance to the cephalic spines. Such spines are a common feature in the planktonic young of recent Crustacea, and their presence and strong development in the young of Leptoplastus and in the adult Olevelloides is to be regarded as associated with the mode of life in those forms. Apart from the presence of the three pairs of spines, there is very little resemblance between these two genera, which have no relationship one to the other. If these three pairs of spines had any phylogenetic significance, they would have occurred much more frequently in the early developmental stages of Trilobites. Their occurrence is, however, the exception rather than the rule.

Among the Mesonacidæ, the young of Olenellus gilberti alone is known to possess all three pairs of spines. The anterior pair is



Diagrammatic Outlines of relatively Primitive Examples of Trilobite Cephala, showing the Composition and the Disposition of Homologous Parts.

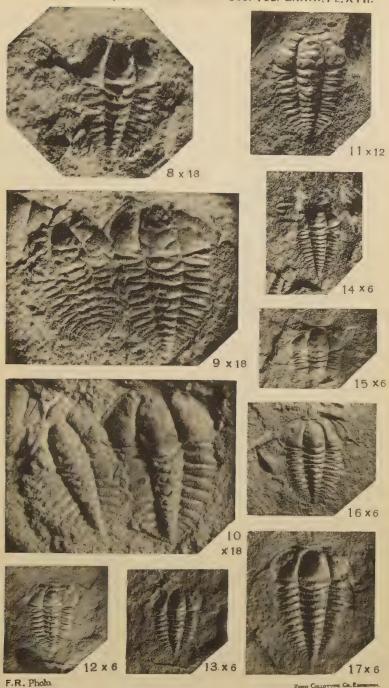




LEPTOPLASTUS SALTERI: Early Meraspid Development (Degrees 1-4).

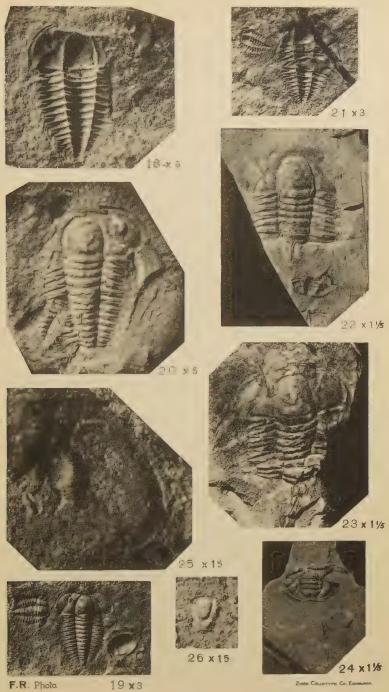


QUART. JOURN. GEOL. SOC. VOL. LXXXI, PL, XVII.



LEPTOPLASTUS SALTERI: Later Meraspid Development (Degrees 5-11).





LEPTOPLASTUS SALTERI: Holaspid Development (Degree 12).



unknown in other Mesonacidæ, and therefore cannot have revolved to a posterior position, as postulated by the Author. On the other hand, in Wanneria halli the 'middle' pair of spines actually travels from the posterior to an anterior position during development. Nevertheless, this genus, in common with all other Mesonacid genera, has no facial suture. In the general absence of both the anterior facial suture and of anterior spines in the development and in adults of Mesonacidæ, there is very little evidence in support of the Author's view that both these structures have travelled

backwards to the posterior margin of the cephalon.

Prof. V. C. ILLING congratulated the Author on a valuable addition to our knowledge of the development of the Trilobites. Records of the ontogeny of particular genera were all too few, and he welcomed the Author's new facts as clearing up points hitherto obscure. With regard to the more theoretical deductions, the speaker would rather adopt a more cautious attitude, in view of his own experience when dealing with isolated specimens of early development among the Middle Cambrian trilobites of Hartshill. There was a great temptation to draw analogies, which further evidence only too often falsified. At this stage of our knowledge, the speaker believed a better purpose would be served by collecting facts. His own collection of forms of Paradoxides hicksii confirmed and completed the evidence of the gradual forward growth of the glabella, until in the last stage the anterior margin was completely eliminated in its medial portion.

The AUTHOR, in answer to Prof. Swinnerton's criticisms, stated that reference to Olenellus gilberti, though it was specially illustrated by one of the slides, had been passed over in the demonstration through lack of time. Olenelloides armatus and the larvæ of Olenellus gilberti, in which the three pairs of spines were lateral in position, were regarded to that extent as reversions to the primitive condition; and this was rather supported by the fact that the lateral position of the spines was unaccompanied by any dorsal facial suture, such as occurred in the Heptacicephalic Stage of Leptoplastus. The statement that in Wanneria halli the genal spines had migrated from a posterolateral to an anterolateral position was insufficiently supported by Walcott. It was much more probable that the anterolateral spines were the primitively anterior or procranidial spines, such as occurred in Olenelloides and in Olenellus gilberti. Wanneria halli was quite abnormal, and of the nature of a 'sport'.

With regard to Prof. Swinnerton's first remarks,—suggesting that the head-spines were larval accessories, and that one could not be sure of their identity -the Author replied that the definite relation observed between the cranidial and parial spines and the sutures, and the absence of any other peripheral spines besides the occipital, strongly supported the contention that they are definite morphological entities, as claimed in the paper. It had been shown that the metacranidial were the serial homologues of the pleural spines of the thorax; and they, the parial, and the

324

procranidial, are claimed in a forthcoming paper as the serial homologues of the macropleural spines, such as characterize the 3rd and 6th thoracic segments of Olenelloides. There is much evidence in favour of their being ancestral in character, and quite obviously they tended to disappear in several families in the course of evolution, the metacranidial being the last to disappear in Proparial Trilobites, and the parial being the last in Mesoparial Trilobites. This is not to say that larval conditions did not favour the persistence of the head-spines, as compared with adult conditions. As to the difficulty of identifying the different spines, this obtains in the Mesonacidæ alone, and is due solely to the disappearance of the facial suture, which receives a complete explanation in the revolution of the spines.

In reply to Prof. Illing, the Author remarked that he had purposely limited the paper to the ontogenies of the more primitive Trilobites, in which the segmentation of the glabella is still evident.

10. A COMPOSITE DYKE from EASTERN ICELAND. By Miss EILEEN MARY GUPPY, B.Sc., F.G.S., and LEONARD HAWKES, M.Sc., F.G.S. (Read December 3rd, 1924.)

[PLATES XIX & XX.]

CONTENTS.

		Pag
I.	Introduction	325
II.	Field Description	325
III.	Petrology	328
IV.	Origin of the Quartz- and Felspar-Xenocrysts in the Dolerites	
\mathbf{v} .	Origin of the Basic Inclusions in the Acid Rocks	335
	The Sequence of the Intrusions	
	Summary	339
III.	Appendix, by Prof. H. HILTON, M.A., D.Sc., on the	
	Cooling of a Dyke	340

I. Introduction.

A copious literature exists relating to the phenomena of composite dyke-and-sill intrusions, mainly based on a study of the Tertiary rocks of Ireland and Scotland. Composite sills have not yet been noted in Iceland, but composite dykes occur quite commonly in the Tertiary plateau-basalt series of the eastern part of the country. Most of them illustrate characteristics which have been reported from elsewhere, and no detailed account of them is desirable. The dyke here described exhibits, however, some unique features, which have seemed to us to warrant investigation.

The field work was carried out by the second-named author, during summer visits to Iceland in 1914, 1920, 1922, and 1924.

The only reference in literature to this occurrence is a note by Th. Thoroddsen 1 of a 'liparite-dyke,' full of basalt-fragments, bordered on each side by basaltic dykes.

II. FIELD DESCRIPTION.

The outcrop gives rise to a deep cleft, in the cliffs on the north side of Breithdalsvik, known as Hökulvikurgil (Pl. XIX, fig. 1), about 300 yards east of Snaehvammur farm. The exposure of rock in the gill is continuous from sea-level to the summit of the ridge between Breithdal and Stothvarfjord—about 2400 feet high, with the exception of a break between 15 and 300 feet which is covered by talus and raised-beach material, and another at 400 feet due to gill-deposits.

The country-rocks are plateau-basalts, with partings of red

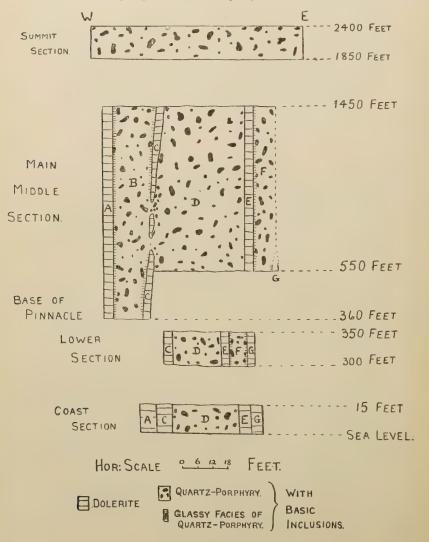
¹ 'Island' Ergänzungsheft No. 152, Peterm. Mitt. 1905, p. 277.

lateritic rock, and a massive dolerite-sill comes in between 1450 and 1850 feet. The outcrop trends 7° east of north. It does not mark a fault-plane.

The exposures are illustrated in the diagrammatic elevation of fig. 1, and will be briefly described from bottom to top: that is,

from south to north.

Fig. 1.—Diagrammatic elevation of the Hökulvikurgil dyke, illustrating exposures of the dyke from sea-level to summit.



At the coast the outcrop is marked by an inlet, the site of an acid intrusion bounded by dolerite-dykes. This exposure is displaced westwards with reference to the line of the main gully. The two dolerites on either side have been cut into by the sea along their junctions: the easternmost dolerite shows a tachylytic border to the country-rocks. The quartz-porphyry varies in thickness from 40 to 25 feet within a few yards.

Above the raised-beach platform, the 'lower section' shown in Pl. XIX, fig. 2 is seen at the entrance to the gully. The quartz-porphyry 'D' is rudely columnar, variable in thickness (16 to 21 feet), and holocrystalline at the contacts with 'C' and 'E'. The porphyry 'F' shows a chilled glassy margin, 6 inches thick in

places, at the junction with dolerites 'E' and 'G'.

After a break in the outcrop due to a deposit of stream-débris, the main exposure is reached. At the base of the pinnacle (Pl. XIX, fig. 2) the quartz-porphyry shows a glassy phase, reaching 9 inches

in thickness, in contact with the dolerites.

At 550 feet the full breadth of the dyke is exposed, and it is seen to be composed of seven members—the dolerites alternating with the quartz-porphyries. The quartz-porphyries have weathered out, leaving the inner dolerites standing as walls; the pinnacle is of dolerite 'C'. Columnar structure is developed in all members, but more notably in the dolerites. The varying thicknesses of the acid members are a marked feature, and at the base of the main section the dolerite 'C' has a very irregular occurrence—in one place it diminishes rapidly from $2\frac{1}{2}$ feet to thin out altogether, showing the quartz-porphyries 'B' and 'D' to be one and the same rock-mass. A marked feature is the absence of a chilled phase at the cheeks of 'D', and its almost constant presence on either side of 'B' and 'F'. The dolerite 'G' is not present in the upper part of the main section. The quartz-porphyry 'B', which is $7\frac{1}{2}$ feet thick at a height of 360 feet, is 16 feet at 1300 feet, and has a $3\frac{1}{2}$ -foot glassy border to 'C'.

Immediately beneath the basic sill, débris obscures the section. The sill is 400 feet thick, and does not appear to be cut by any of

the dyke members.

Above the sill the quartz-porphyry forms the whole of the dyke, being 85 feet broad at the top of the ridge, with a border of chilled rock $1\frac{1}{2}$ feet thick to the country-rocks at its eastern end.

The irregular curvature of the dyke-fissure and of its several members is not shown in fig. 1 (p. 326), but can be seen in the

photographs reproduced in Pl. XIX.

The acid members — quartz-porphyry and pitchstone — are crowded with inclusions of basic rock. The larger inclusions average a few inches in diameter, and are commonly of angular form. A notable feature is furnished by the innumerable fragments 2 to 5 mm. in diameter, with sharp boundaries to the enclosing acid rock. The distribution of the inclusions is extremely even throughout the three members 'B', 'D', and 'F'. Measurement showed that they form 10 to 20 per cent. of the rock—and there is no indication of variation of content with height.

At 600 feet, where there is a gap in the dolerite 'C', an unusually large number of inclusions was seen near the dolerite, several giving elongated sections parallel to the dyke-wall, and it is clear that some of these are fragments shattered from the dolerite. Otherwise, there appears to be no falling-off in the content of inclusions towards the middle of the acid members. The inclusions are of compact dolerite; none were seen similar to any of the vesicular lavas and red interbasaltic beds of the country-rocks.

III. PETROLOGY.

The Acid Rocks.

Quartz-porphyries.—These show abundant phenocrysts of quartz and felspar set in a microcrystalline ground-mass. Green pyroxene-phenocrysts occur very sparingly, and a colourless pyroxene is fairly common, with magnetite and zircon. Granophyric intergrowths of quartz and felspar occur as phenocrysts in the rock. One crystal of allanite was seen (No. 227'').

The quartz-phenocrysts, which form 7 per cent. of the rock, are euhedral, and in many cases show peculiar shapes due to resorption. They occur commonly in groups of two or more individuals.

The felspar-phenocrysts, forming 4 per cent. of the rock, are generally tabular in shape. They are mostly untwinned, but some show twinning after the Carlsbad law. The mineral is biaxial and negative:—refractive index $\beta=1.521\pm0.001$; $\gamma-\alpha=0.00531$ and $\gamma-\beta=0.00056$ (determined with the Berek compensator); the optic axial plane is \parallel (010) in some crystals and \parallel (001) in others; $2Va=40^{\circ}\pm3^{\circ}$ (determined by direct measurement of 2E), and $2V\alpha=38^{\circ}$ (calculated from the birefringence).

The felspar-crystals were examined microchemically by treatment with hydrofluoric acid—control tests being carried out on sanidine, albite, and anorthoclase (from Pantelleria). Results indicated that soda is present in the Hökulvikurgil felspar, but in an amount distinctly subordinate to potash, the proportion being much smaller than that in the Pantellerian anorthoclase, or in a

mixture containing equal amounts of sanidine and albite.

The mineral probably comes within the group known as sodaorthoclase, using this term to denote those felspars in which the soda-felspar content varies from 10 to 30 per cent.² Many sanidines come within this group, and the small optic axial angle of the felspar shows that it is allied to them. The factors which determine the axial angle of the potash-soda series of felspars are not, however, clearly established.

¹ The numbers in parentheses refer to rock-specimens and thin sections in the Museum of the Geological Department, Bedford College, Regent's Park, N.W. 1.

² H. L. Alling, 'The Mineralography of the Feldspars' pt. i, Journ. Geol. vol. xxix (1921) p. 232.

The felspar-phenocrysts frequently exhibit irregular shapes and holes due to resorption, as do the quartzes (Pl. XX, fig. 3). Another interesting feature, especially notable in the partlyresorbed felspars of both lithoidal and glassy rocks, is their weathered appearance. This is sometimes exhibited around the borders of the crystals and their internal cavities, and sometimes throughout them. These crystals present a similar appearance to the albite figured by A. L. Day & E. T. Allen, which had been partly melted (see their pl. xix). The first evidence that those authors obtained of melting was the formation of a 'weathered or toothed' appearance, which subsequently gave rise to the development of glass in 'tiny pockets and lanes' (op. cit. p. 51). We ascribe the weathered appearance of the phenocrysts of the acid rocks to incipient melting. In the felspar-xenocrysts of the dolerites the melting has advanced a stage farther, and the development of glass has resulted in the splitting-up of each crystalsection into innumerable tiny areas of felspar all extinguishing simultaneously, and giving rise to a finger-print structure (Pl. XX, fig. 4) which is not unlike that exhibited by the albite described by Day & Allen. It is clear, from their irregular shapes, that resorption of both the quartz and the felspar of the acid rocks occurred before solidification of the magma, and this may have been due to release of pressure on intrusion. The soda-orthoclases frequently show clear borders, representing a subsequent further growth of felspar (Pl. XX, fig. 3).

A striking feature is the curved habit of some of the sodaorthoclase crystals. The curvature is commonly quite even throughout the length of the crystal-sections, being more evident in the longer ones. Their extinction varies evenly from end to end, and differences were determined of up to 34°, which is a measure of the bending. The transverse cleavages are prominent in such crystals (see Pl. XX, fig. 2). In one case the curvature is accomplished within a comparatively narrow band in the middle of the crystal-section, and microscopic twinning can be seen in this band.

These crystals may be grouped with the 'bent crystals' of L. J. Spencer's classification (op. cit. p. 269), as they have been bent subsequent to their growth. Curved isolated felspar-phenocrysts, surrounded by the glassy or finely crystalline ground-mass of an igneous rock, do not seem to have been observed before. Day & Allen have shown that felspar-fragments can be bent under a slight load at high temperatures, and the photographs that they give of these crystals (op. cit. pls. xxiv, xxv. & xxvi) demonstrate the similarity of the crystals to the soda-orthoclases of the dyke. The large areas of glass seen in some of the artificially bent fragments are not visible in the naturally occurring bent felspars, although many of these present the weathered appearance which we have ascribed to melting.

¹ 'The Isomorphism & Thermal Properties of the Feldspars' Carnegie Inst. Publication, No. 31, 1905.

² 'Curvature in Crystals' Min. Mag. vol. xix (1920–22) p. 263.

Day & Allen point out that, in their experiments, 'the order of magnitude of the viscosity of the molten portion is the same as that of the rigidity of the crystals' (op. cit. p. 52), and if this had been the case on intrusion of the acid magma into the dyke, the bending may be ascribed to the flow of the very viscous magma bearing the felspar-phenocrysts. The even size and distribution of the large felspars throughout both lithoidal and glassy facies proves that they had grown before intrusion, and we regard their curvature to be of the same character and origin as the curved flow-bands often seen in acid lavas.

The presence of mineralizers and other components would perhaps lower the viscosity of the magma, as compared with the felspar-glass, but the lower temperature and greater pressure may compensate for this. The curved crystals are of commoner occurrence in the glassy portions of the quartz-porphyry, and some movement may have taken place after the chilling had occurred, in what would then have been an abnormally viscous magma.

The green pyroxene is similar to that which occurs fresh in the glassy types, but is here pseudomorphed.

The microlites of the ground-mass are of quartz and felspar.

Specific gravity determinations were made with the specific-gravity bottle. In the case of the quartz-porphyry, the rock is porous and crowded with basic fragments. In order to determine the specific gravity of the quartz-porphyry apart from the inclusions, the rock was crushed; the less-contaminated fragments were selected and ground, and the lightest material, being mostly derived from the inclusions (which are more weathered than the enclosing rock), was removed from the powder by decanting with water. In this way the following values (referred to 4°C.) were obtained: top rock (No. 8)=2·609; intermediate rocks—'B' (No. 227)=2·603, 'D' (No. 229)=2·610; coast rock (No. 103)=2·608.

The results are remarkably uniform, showing the quartz-porphyry to be constant in composition throughout the vertical extent of the dyke, from sea-level to an altitude of 2400 feet.

Chilled glassy margins.—The phenocrysts in these rocks are similar to those of the quartz-porphyries, except that the green pyroxene, which is still very sparing, occurs here in a fresh condition. It is present in the form of small euhedral crystals, having good cleavages, and in some cases showing central twin-bands parallel to (100). $\gamma - \alpha = 0.022$, indicating an approach to hedenbergite in composition. Several of the crystals show well-marked resorption-borders. Among the quartz-phenocrysts one was noted having a border of pyroxene, iron-ore, and felspar (Pl. XX, fig. 6). This pyroxene appears to be a reaction-product.

A single large euhedral phenocryst occurs in one of the sections

(No. 105') of a brown, biaxial, negative mineral, which is an allanite elongated parallel to the 'c'axis. The section is approximately $\|(010)$, and shows a good cleavage $\|(001)$; twinning on (100); negative elongation; strong pleochroism: γ' dark reddishbrown, α' brownish-yellow; birefringence=about 0.014; extinc-

tion-angle $a^c = 37^\circ$.

These properties indicate an allanite which contains a large proportion of cerium epidote. A similar, smaller crystal is present in one of the sections of quartz-porphyry (No. 227"). The area of 60 square cms. of acid rock examined contains only 0.2 sq. mm. of allanite, all of which is concentrated in two crystals. This sparse distribution indicates that they are not normal crystallizations of the rock in which they now occur, and it illustrates a feature of the occurrence of allanite in igneous rocks which has been noted before 1 (op. cit. p. 110).

The glassy base is crowded with microlites of felspar and pyroxene; with the latter are associated minute grains of iron-ore.

The chilled rock which forms the eastern periphery of the dyke at its summit is dark and fine-grained in hand-specimen, and has a high specific gravity (2.62). In thin section it is seen to contain an unusually high proportion of basic inclusions, together

with some large crystals of basic plagioclase.

Soda-orthoclase phenocrysts are abundant; quartz-phenocrysts are less common; granophyric intergrowths of quartz and felspar occur. The ground-mass is an acid glass, and contains many felspar-laths, small augite-crystals, and grains of iron-ore. Green pseudomorphs after olivine (?) are present. This rock is unlike the other chilled specimens, and shows evidence of interaction with a basic rock and 'strewing about'.

The specific gravities (referred to 4° C.) of the glassy rocks are as follows:—'B°C' (No. 9)=2·479, 'B°A' (No. 107)=2·496, 'F°E' (No. 13)=2·480. These values, when compared with those of the quartz-porphyry (above), show that the glassy varieties are normal chilled phases of that rock. The pitchstone 'B°C' (specific gravity=2·479) shows a 5·20 per cent. increase in volume, when compared with the quartz-porphyry (specific gravity=2·608). The slightly irregular increases in volume given by the glassy varieties as a whole (4·48 to 5·20 per cent.) may be put down to the varying content of xenolithic dolerite.

The uniformity of composition of these rocks, which are predominantly composed of glass from different contacts, is also indicated by the similar values given by the different specimens for the refractive index: that is, 1.49 to 1.50. This provides a better indication of composition than the specific gravity determinations, as it is not affected by the presence of the basic xenoliths. The constancy in composition shows that no appreciable

¹ J. P. Iddings & W. Cross, 'On the Widespread Occurrence of Allanite as an Accessory Constituent of many Rocks' Amer. Journ. Sci. ser. 3, vol. xxx (1885) p. 108.

assimilation has occurred at the contacts, otherwise the specific gravities and refractive indices would have given higher and variable values.

Basic rocks.—The constituent minerals of the dolerites are augite, a basic felspar, and iron-ore, the latter being generally in the form of skeleton crystals. Dykes 'A' and 'G' are amygdaloidal, the amygdales being filled with calcite. Glass occurs in many cases in the ground-mass, and is generally brown.

The rocks are of medium grain, with fine-grained marginal facies, and show typical porphyritic ophitic intergrowths of augite

and felspar; glomeroporphyritic clots of felspar also occur.

The felspar of the dolerites varies in composition between hytownite (porphyritic individuals) and labradorite (ground-mass).

Many of the larger individuals are zoned.

In the dolerite 'C', it is interesting to note that small olivinecrystals occur in the fine-grained chilled facies, but are absent from the slowly-cooled, more coarsely-grained rock. This is an interesting illustration of how the presence or absence of olivine in a rock may be dependent upon conditions of cooling.

Inclusions of fine-grained olivine-dolerite occur in the more

coarsely-grained types.

In one or two sections, small groupings of quartz-lamellæ, forming paramorphs after tridymite, were seen to be associated with calcite in the more weathered parts of the ground-mass.

The specific gravities (referred to 4° C.) of the basic rocks are as follows:—Dolerite 'A' (No. 226) = 2.871, coarse-grained 'C' (No. 10) = 2.964, fine-grained 'C' (No. 11) = 2.931, 'E' (No. 12) = 2.971, 'G' (No. 4) = 2.931.

Xenocrysts.—Xenocrysts of quartz are irregularly distributed through the basic rocks, together with tabular crystals which correspond in their optical characters and general appearance with the soda-orthoclases of the quartz-porphyries. No xenocrysts were found in 'G', and no felspar in 'A'. In most cases xenocrystic soda-orthoclases are surrounded by a clear border showing lamellar twinning; this apparently represents a secondary deposition of basic felspar (Pl. XX, fig. 5). The development of glass throughout these felspars has already been described (see p. 329). The quartzes commonly exhibit corroded outlines, and reaction-borders consisting of minute prisms and grains of monoclinic pyroxene.

In some sections rounded aggregates of granular pyroxene occur, suggesting complete resorption of the original quartz-xenocryst; in a few cases a little quartz remains unaltered in the centre of the aggregate.²

¹ L. Hawkes, 'On Tridymite & Quartz after Tridymite in Icelandic Rocks' Geol. Mag. 1916, p. 205.

² J. S. Diller, A Late Volcanic Eruption in Northern California, Bull. U.S. Geol. Surv. No. 79 (1891) p. 25.

Basic inclusions in the acid rocks.—Basic inclusions are abundant throughout all the acid types, being present in every thin section. They show the usual minerals—basic felspar, augite, magnetite, and sometimes olivine, together with a good deal of secondary chloritic and other material. Some of the larger felspars have their central portions very weathered, but are surrounded by a clear border of fresh material which shows lamellar twinning. Much of the felspar and augite occurs together in ophitic intergrowth.

Xenocrysts of quartz are present in the inclusions. They show reaction-borders consisting of minute prisms of pyroxene.

It is noticeable, even in thin section, that the boundaries of the xenoliths with the enclosing acid rock are in all cases well-defined.

IV. ORIGIN OF THE QUARTZ- AND FELSPAR-XENOCRYSTS IN THE DOLERITES.

It is evident that the quartz and soda-orthoclase crystals occurring in the dolerites are xenocrystic in nature, and cannot be regarded as resulting from normal crystallization of the basic magma. The irregular distribution of the quartzes, and their association with the acid felspar, both point to this conclusion, which is further supported by the similarity of both to the normal phenocrysts of the associated acid rock.

Dr. A. Harker has marshalled the evidence supporting the contention that in cases similar to the one here described, the quartz has crystallized in the magma which gave rise to the acid rock, and with this conclusion we agree. The incorporation of the quartzes in the basic rock is ascribed by him to their sinking into

the basic magma from the overlying acid one.

This assumption has been criticized on general grounds.² For the present case, the density of the dolerite 'E', in which the quartz is found, is 2.971 at 4° C. Determinations based on experiments carried out by A. L. Day, R. B. Sosmann, and J. C. Hostetter indicate that at 1100° C. the density of the magma from which this dolerite crystallized would be 2.60 (op. cit. p. 27). The densities given by Prof. R. A. Daly for basic magmas 4 are probably too high; the figure given is in accord with Barus's determinations. The presence of volatile constituents would lower this value, but they are present in small amount only in basic magmas, and it is highly improbable that the correction would bring the value near to that of the quartz, which at 1100° C. is 2.53, while that of the felspar is less. It is clear that any sinking of these crystals in the magma was impossible.

¹ On Porphyritic Quartz in Basic Igneous Rocks' Geol. Mag. 1892,

p. 106.

3 'The Determination of Mineral & Rock-Densities at High Temperatures' Amer. Journ. Sci. ser. 4, vol. xxxvii (1914) p. 1.

4 'The Mechanics of Igneous Intrusion' ibid. vol. xxvi (1908) p. 17.

p. 485.

² L. Hawkes, in the Discussion (p. 112) on the paper by S. H. Reynolds, 'The Igneous Rocks of the Tortworth Inlier' Q. J. G. S. vol. lxxx (1924) p. 106.

A different view as to the origin of quartz- and acid felsparxenocrysts in a basic rock was put forward by the late Prof. G. A. J. Cole to explain their occurrence in the composite dyke at Glasdrumman Port.¹ Here the earlier intrusion was an andesite, and this was invaded later by a central mass of eurite. The marginal zones of the andesite contain crystals of quartz and orthoclase up to 10 or 12 cm. from the junction of acid and basic rocks, and, according to Cole, their presence is due to the partial remelting of the andesite by the invading eurite, with absorption of material from the eurite, the porphyritic crystals of the latter remaining undestroyed. The marginal zones of the andesite are shown to be intermediate in composition between the acid and the basic members, and this is in accordance with the explanation offered.

In the Hökulvikurgil dyke it has been shown that no mixing at the contacts has taken place, and the xenocrysts occur in normal dolerite—as the thin sections and gravity determinations show.

The xenocrystic content does not increase towards the margins. It is found, on the contrary, that in the normal central dolerite ('C' No. 228) the xenocrysts constitute 0.6 per cent. of the rock, while in the fine-grained facies ('C' No. 11) they constitute only 0.17 per cent. The suggestion is made that

'the basic magma had caught up portions of the acid one in which the large quartz and felspar had already grown, and that, before the consolidation of the dolerite, the acid liquor had been assimilated and the crystals attacked' (L. Hawkes, Q. J. G. S. vol. lxxx, 1924, p. 112).

The felspar-xenocrysts of the dolerites show a greater development of glass than the phenocrysts of the acid rocks (see p. 329), which difference may be explained as due to melting caused by the higher temperature of the basic magma that absorbed the acid liquor.

Measurements of the xenocrystic content of the dolerite were made, in order to explore the applicability of this conception, and to determine the degree of mixing necessary. The results are set forth in the following table:—

TABLE I.—PERCENTAGE XENOCRYSTIC CONTENT OF DOLERITES.

			2707 7 7700
Dolerite 'C'.	Quartz.	$Soda\mbox{-}Orthoclase.$	Totals.
No. 228 No. 11	0·6 0·1	0·36 0·07	0.96 0.17
Dolerite 'E'. No. 233' No. 12 No. 1	0·07 nil 0·37	nil 0·06 0·21	0·07 0·06 0·58
Average	1.14	0.70	
Ratio $\frac{\text{Quartz}}{\text{Felspar}} = 1$	1.63,		

^{[•.1 &#}x27;On Derived Crystals in the Basaltic Andesite of Glasdrumman Port (Co. Down)' Sci. Trans. Roy. Dublin Soc. ser. 2, vol. v (1894) p. 239.

The amount of quartz is greater than that of the felspar in both dolerite and porphyry, considering the xenocrysts in the former case and porphyritic crystals in the latter. It is found that the ratio of quartz to soda-orthoclase in the dolerite is 1.63:1; for the quartz-porphyry it is 1.75:1. This is a close agreement. The distribution of xenocrysts in the dolerite is very irregular, as the table shows.

If we wish to estimate the amount of admixture necessary, the average xenocrystic content of the dolerite must be known. This is difficult to determine; 0.5 per cent. is a fair maximum value, 0.2 per cent. is probably nearer the truth. The total amount of porphyritic constituents in the porphyry is 11 per cent. An admixture of 1 part of porphyry with 21 parts of dolerite would be required, taking the maximum value of 0.5 per cent. for the xenocrystic content. Taking the more probable value of 0.2 per cent., the requisite mixture is that of 1 part of porphyry with 54 parts of dolerite.

These values cannot be greatly affected by the slight absorption of the xenocrysts which has taken place. Obviously, the amount of acid magma caught up has been relatively small, and insufficient to alter materially the composition of the dolerite.

Thus the xenocrystic content and the general character of the

dolerite are in accordance with the suggested origin.

We are indebted to Mr. W. H. Herdsman for the following determination of the silica content of the dolerites:—'G' (No. 4) = 45.65 per cent., 'C' (No. 11) = 51.90 per cent. If the dolerite 'G' represents the magma which incorporated some of the acid magma to produce the rock 'C', a greater degree of admixture must have taken place. However, this assumption may be incorrect, and the xenocrysts give a more reliable indication of the admixture that obtained.

A similar explanation to our own of the presence of quartz- and felspar-crystals in dolerite is given by W. R. Smellie in his account of a composite sill from Bute.¹

V. ORIGIN OF THE BASIC INCLUSIONS IN THE ACID ROCKS.

These represent shattered dyke-rock. No fragments of country-rock were noted, and the occurrence of quartz- and felspar-phenocrysts in the inclusions supports the view that the latter have been derived from the earlier dolerite-dykes. With the exception of the few fragments occurring where the dolerite 'C' thins out, it is not suggested that the shattering took place where the quartz-porphyry now occurs. If such had been the case, the dolerite-dykes would not have survived with their even thicknesses, cleancut borders, and freedom from acid veins. Neither would the distribution of the fragments have been so independent of the proximity of the rock to the dolerite. There is evidence to show that intrusion may have come from the north, in which connexion

¹ 'The Tertiary Composite Sill of South Bute' Trans. Geol. Soc. Glasgow, vol. xv (1915) p. 125.

the absence of the dolerite-dykes from the north of the outcrop is significant. It is suggested that, in some other place, the acid magma forced its way through the basic dykes with explosive force, completely shattering these into tiny fragments, with very thorough mixing of the whole, and then the inclusion-bearing magma was intruded into its present position. The mixing occurred during the escape of the explosive gases, and the viscosity of the resultant magma prevented any settling of the inclusions, which, although much denser than the magma, show no sign of aggregation at the base of the 2100 feet exposed. Additional evidence of the great viscosity of the magma has been adduced from the occurrence of the bent felspars (p. 330). The accompaniment of explosive action and acid magmatic intrusion may be associated with the greater gaseous content of such magmas. No crustal movement would seem to be adequate to explain the shattering, and the dyke does not mark a fault-plane.

We have found no reference in literature to similar inclusionbearing dykes, but another example can be seen in Faskrudsfjord, north of Breithdal, east of the town. On either side of the fjord is a composite dyke, with two outer dolerites and an inner quartz-

porphyry crowded with basic inclusions.

VI. THE SEQUENCE OF THE INTRUSIONS.

Applying the normal interpretation of multiple dykes to the case described, the order of intrusion would be (1) dolerite 'AG'; (2) quartz-porphyry 'BF' in the middle of 'AG'; (3) dolerite 'CE' in the middle of 'BF'; and (4) quartz-porphyry 'D' in the middle of 'CE.'

The presence of chilled phases of 'B' and 'F', to 'C' and 'E'

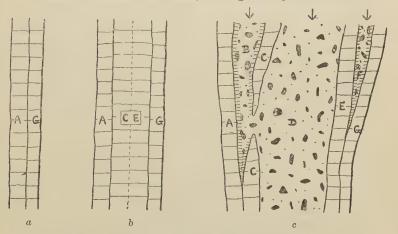
respectively, shows that this order was not followed.

That all the acid members resulted from the same intrusive act is evident from the field and petrological evidence. The outcrops of 'B' and 'D' are continuous in parts of the section, as already described, and the identity of the acid rocks is indicated by their petrological character, and especially by the common feature of the basic inclusions. The various basic intrusions came first, the acid magma bearing the inclusions being the final one to arrive. At the coast it came up in the middle of the dyke. In the main part of the section it came up in the middle of 'C E'; it also broke across these, and made its way between the two dolerites on either side. The sequence of events is illustrated in fig. 2. As might be expected, the thicknesses of the acid dykes are variable. The greater thickness of the quartz-porphyry on the north, and the thinning-out of 'B' and 'F' on the south, may be due to intrusion from the north. The width of the dyke is 85 feet at the summit, 68 feet in the middle, and decreases to 48 feet at the coast. This decrease in total thickness is due to a variation in the thickness of the quartz-porphyry.

The distribution of the chilled phase of quartz-porphyry about

the dolerites 'C' and 'E' is significant—it is present at their outer but not at their inner cheeks. This can only be taken to indicate that the inner cheeks were hotter than the outer cheeks, and shows that 'C' and 'E' represent one intrusion, which was followed by the penetration of the acid magma along its middle and outer parts before the former had cooled down. The suggestion has often been made that the central member of a multiple dyke has been intruded into the still hot middle of the previous intrusion. In the case described, the accident whereby the later intrusion has taken place on each side of the two boundary-walls affords a confirmation of this view.

Fig. 2.—Diagrams illustrating the sequence of the intrusions.



a=Intrusion (separately) and cooling of dykes A and G.

b=Intrusion of dolerite between A & G.

c=Invasion by acid magma before the completion of the cooling of the middle of C E.

A case of local rapid cooling of an intrusion, shown by the distribution about it of the chilled phases of a subsequent intrusion—their presence at contacts which were cold, and their absence at other contacts which were still hot—is described by Mr. E. B. Bailey from Arthur's Seat, Edinburgh.

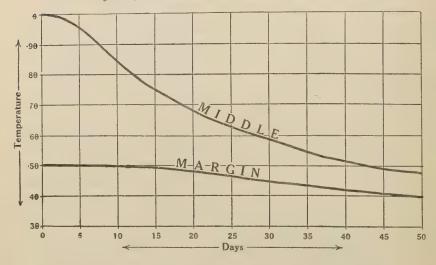
It was thought that some indication might be obtained regarding the suggested explanation of the phenomena, from a calculation of the rate of cooling of different parts of a dyke, and we are indebted to Prof. H. Hilton for his examination of the problem (see Appendix, § VIII, p. 340).

¹ 'Volcanic Vent Parasitic on St. Leonard's Sill' Trans. Edin. Geol. Soc. vol. xi (1923) p. 223.

We have drawn a graph (fig. 3), based on the results given by Prof. Hilton, which provides us with some guide as to the possible differences of temperature to be expected between the outer margins and the middle of a cooling dolerite dyke 3 metres (9.84 feet) thick.

The time of cooling will be greater than that calculated, as the latent heat is disregarded; but, on completion of crystallization, the temperature differences will not be very different from those tabulated. The amount of differential chilling of the invading acid magma at the centre and the margins of the dolerite is

Fig. 3.—Graph illustrating the rate of cooling of the middle and margins of a dolerite-dyke 3 metres (9.84 feet) thick.



governed by the temperature of the intruded basic magma which must not be too high, and that of the succeeding acid magma which must not be too low:—that is, the basic magma-temperature halved must be lower than that of the acid magma. Also, the time which elapses between the two intrusions must not be great.

Taking a temperature of 1000° for the basic magma, and assuming the acid magma to be at 700°, the amount of chilling of this magma at the margin of the dolerite would be 100°. This chilling is small in amount, but might suffice to produce the glass, were the acid magma near the temperature of its complete solidification—which is not unlikely, seeing that the quartz and felspar had already grown in it. If the contention of some American petrologists be accepted, that the quartz of some basalts represents a normal early stage of the crystallization of the rock, we must allow that the temperature of the basic magma may have been

considerably lower than the values that we have suggested, thus

producing a greater chilling.

It is assumed that the basic magma was intruded as a whole at one time. The occurrence of inclusions of fine-grained dolerite in the coarser, indicates, however, that the central part of the dyke came up after a certain marginal phase had crystallized, and, if this took place, the differences of temperature between margin and centre would be increased.

If the conclusions arrived at from the field evidence are sound, the intrusions of the two magmas must have been separated by an

interval of days and not months.

Petrological literature contains abundant examples of xenocrystic phenomena similar to that which we have described, and, if the explanation that we have offered is of wider application, it is clear that the association in the crust and subsequent mixing of extreme magmas is not of uncommon occurrence. Dr. Harker's conception of an acid magma directly overlying a basic one, while not a necessary consequence of our hypothesis, may be suitably incorporated in it. The earlier intrusion of the heavier portion is probably due to its greater fluidity: relief of pressure being first obtained by the draining-off of the lower mobile fraction, which would draw some of the overlying liquor with it, and, finally, the expulsion of the viscous acid remnant.

VII. SUMMARY.

The dyke is exposed in a cliff-section 2400 feet in height, at Hökulvikurgil, Breithdal (Eastern Iceland). It is composed of basic and acid rocks, and in part of the section consists of seven members, dolerites alternating with quartz-porphyries, the central member being a quartz-porphyry. The distribution of the chilled facies of the acid members is significant, these being absent from the central quartz-porphyry, whereas pitchstone borders each side of the two outer acid members. Evidence is given to prove that the acid members resulted from one intrusive act, whereby the magma came up in the middle and also at the sides of the preceding basic intrusion, which had only in part cooled down, being hotter in the middle, with the resulting distribution of the glassy facies at the outside contacts only.

The acid members are crowded with inclusions of basic rock. These have a regular distribution, and it is suggested that they originated through the shattering of basic dyke-rock in some other place by explosive action, and incorporation of the fragments in

the magma before intrusion into its present position.

The felspar of the quartz-porphyry is a soda-orthoclase presenting a weathered appearance due to incipient melting, and some of the crystals have been bent subsequent to their growth on account of flow of the viscous magma on intrusion.

Quartz- and soda-orthoclase-xenocrysts are distributed unevenly through some of the dolerites of the dyke, and their origin is referred to the accidental incorporation of a small proportion of the acid phenocryst-bearing magma by the basic one, previous to intrusion.

It is suggested that the order of intrusion of the basic and acid

magmas was governed by their relative viscosities.

Note.—Since the above was written, the Mull Memoir (Geol. Surv. Scotland, 1924) has appeared, in which the phenomena of composite intrusions are discussed. An explanation is given (op. cit. p. 33) of the prior uprise of the basic magma similar to that which we have suggested.

VIII. APPENDIX: ON THE COOLING OF A DYKE. By Prof. H. Hilton, M.A., D.Sc.

The physical conditions of a dyke on and after intrusion are so little known, that we cannot hope to obtain precise information as

to the rate of cooling by mathematical calculation.

We make the assumptions (1) that κ is the same for the country-rock and the dyke, where $\kappa = K/c\rho$, ρ being the density, c the specific heat, and K the conductivity, (2) that the dyke and country-rock obey the ordinary laws of heat-conduction, so that lack of homogeneity, latent heat of crystallization, etc. are neglected. These assumptions are, of course, inaccurate, but may enable us to obtain a rough approximation to the truth.

If θ be the temperature at a point at a distance x from the middle of the dyke in a direction perpendicular to its walls, then,

after an interval of time t,

$$\frac{\partial \theta}{\partial t} = \kappa \frac{\partial^2 \theta}{\partial x^2},$$

which is satisfied by

$$\theta = \Theta(4\pi\kappa t)^{-1/2} \int_{-a}^{a} e^{-(x-u)^2/4\kappa t} du,$$

This is the solution corresponding to the assumption that, when t=0: that is, at the time immediately after the intrusion of the dyke, the width of which is 2a,

 $\theta = \theta$ when $x^2 < a^2$, $\theta = \frac{1}{2}\theta$ when $x^2 = a^2$, and $\theta = 0$ when $x^2 > a^2$.

If we put $u^2 = 4\kappa t v^2$ when x = 0 and $(u - a)^2 = 4\kappa t v^2$ when x = a, we get for the temperatures at the centre and edge of the dyke:

$$2\Theta\pi^{-1/2}\!\!\int_0^n\!e^{-v^2}\!dv, \quad \Theta\pi^{-1/2}\!\!\int_0^{2n}\!e^{-v^2}\!dv,$$

where $4\kappa t n^2 = a^2$.

Taking, for example, $\Theta = 800$, a = 150, K = 004, c = 23, $\rho = 2.8$, we have $t = 900,000/n^2$ in the centigrade and c.g.s. system; wherefore the time elapsed since intrusion is about $10/n^2$ days.

Quart. Journ. Geol. Soc. Vol. LXXXI, Pl. XIX.

Fig. 1.—View of Hökulvikurfjäll from the raised beach.



L. H. photo.

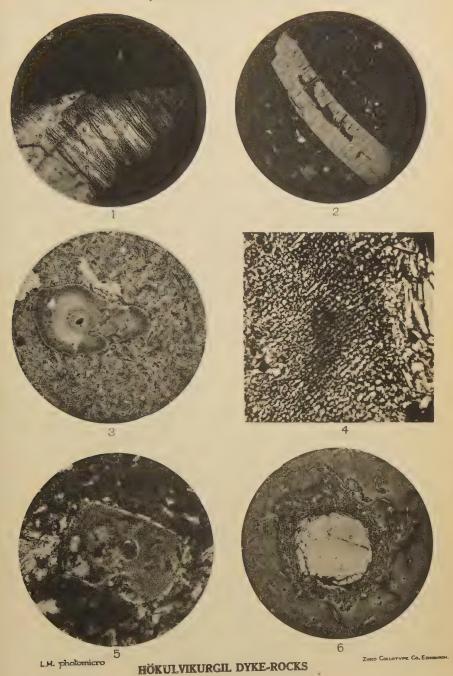
Fig. 2.—View of the entrance to Hökulvikurgil.



L. H. photo.



QUART. JOURN. GEOL. SOC. VOL. LXXXI, PL, XX.





We have then the results, using the tables of $\int_0^n e^{-v^2} dv$ in Appendix II of Brunt's 'Combination of Observations':

Time elapsed in days since								
intrusion	1	5	10	20	35	50	75	100
centre of dyke	800	763	674	548	437	380	311	279
edge of dyke	400	400	398	382	346	319	277	248

These figures are presumed at most to give a rough approximation to the temperatures involved.

EXPLANATION OF PLATES XIX & XX.

PLATE XIX.

Fig. 1. View of Hökulvikurfjäll from the raised beach, showing the gill, the outcrop of the dyke to the summit, and the plateau-basalts.

2. View of the entrance to the gill. The 'lower section' (text-fig. 1, p. 326) occupies the foreground. The columnar structure of the central quartz-porphyry can be seen, also the gully occupied by the porphyry 'F' on the right-hand side. In the background on the left, the country-rock abuts against the dyke 'A'. The dolerite 'C' forms the pinnacle. The curved form of these dykes is well brought out.

PLATE XX.

- Fig. 1. ('F'E'. No. 13.) Soda-orthoclase in pitchstone, showing incipient melting. Nicols crossed. × 115.
 - ('F'G'. No. 106.) Bent crystal of soda-orthoclase in pitchstoneporphyry. The black area in the crystal represents a cavity in the section. Nicols crossed. × 30.
 - 3. ('F'E'. No. 13.) Phenocryst of soda-orthoclase in pitchstone, showing irregular outline, an internal cavity, weathered appearance, and a border of clear felspar. × 35.
 - 4. ('E'. No. 12.) 'Finger-print' structure of soda-orthoclase-xenocryst in dolerite. × 165.
 - 5. ('C'. No. 228.) Dolerite, showing xenocryst of soda-orthoclase with a clear border of secondary basic felspar (see p. 332). × 35.
 - ('FàE'. No. 6.) Pitchstone, showing a quartz-crystal with a border of pyroxene-prisms and grains of iron-ore. Patchy development of brown colour in glass. × 25.

DISCUSSION.

The President (Dr. J. W. Evans) thought that it should not be taken for granted that dykes are intruded from below—Dr. Alfred Harker had shown that in many cases magma had flowed horizontally. He considered that the incipient melting of soda-orthoclases would require a higher temperature than that which usually prevailed in minor intrusions, and that this might be explained by oxidation from oxygen in the clastic volcanic rocks into which they were intruded. He thought it probable that in an acid magma rich in volatile constituents quartz and felspar might sink. Experiments on dry melts did not afford evidence to the contrary. The priority of intrusion of the basic magmas might

be attributed to the fact that the reservoir was tapped near the base, the acid portion above being rendered extremely viscous at the margin by the loss of volatile constituents. He was glad that the Authors adhered to the view that in the presence of much volatile material, especially water, a silicate magma might separate into two non-miscible magmas, one acid with much water and the other basic with little. He thought that this separation probably had occurred on a large scale at an early stage of the Earth's history, and had been repeated on a smaller scale from time to time since.

Mr. A. K. Wells remarked upon the great interest of the paper, in which the Authors had not attempted to make the facts fit orthodox views on petrogenesis. He thought it possible for the xenoliths to have been of local derivation, as one of the basic dykes had apparently been disrupted by the acid magma. If they had been derived from a deep-seated source, the 'Bowen-Andersen effect' should be noticeable, and the speaker asked whether the 'making-over' of the basic minerals which might be expected had been observed. In the specimens exhibited the xenoliths were particularly clearly outlined, and there seemed to have been no interaction between the solid and the liquid, which would be in accordance with the hypothesis of the explosive formation of dykes. He thought that the Authors had made out a good case for the co-existence of the two magmas in the fluid state in a common magma-basin, and, unless fractional crystallization followed by complete re-fusion were postulated, their facts lead back to the principle of limited miscibility.

Mr. W. CAMPBELL SMITH referred to an account written by Mr. E. B. Bailey of a sill near Arthur's Seat, Edinburgh, which, after its upper and lower surfaces had cooled, and after the whole sill had attained a considerable degree of rigidity, had had its central part entirely replaced by a subsequent intrusion of a basaltic magma. He did not think that the presence in the dolerite of xenocrysts of quartz and soda-orthoclase could be regarded as definite proof of the co-existence of the basic and acid magmas in a molten condition. He laid stress on the importance of collecting all the available data of the existence side by side of

basic dolerites and acid quartz-porphyries.

Mr. H. G. SMITH welcomed the return to the theory of the immiscibility of magmas, and said that, pending the arrival of experimental demonstration of its possibility, he was content to accept the evidence supplied by the banded gabbros of Skye. There was no reason to assume the existence of a sharp plane of demarcation between the two liquids in the reservoir; the xenoliths and xenocrysts might be a consequence of imperfect separation possible alternative explanation, he suggested that, if the ideas recently developed by Dr. H. H. Read were applicable, the xenocrysts found in the dolerite, although now lighter than the

¹ Trans. Edin. Geol. Soc. vol. xi (1923) pp. 223-29.

enclosing rock, might, in consequence of exchange of constituents, have had at some period a density sufficient to enable them to sink

in the magma.

Dr. W. R. Jones congratulated the Authors on their interesting and very suggestive paper, and asked whether they thought that it was at all possible for the doleritic part of the composite dyke to have been formed by the crystallization of the basalt of the countryrock, when narrow layers of basalt became surrounded with intrusive acid magma. If that were possible, then a homogeneous acid magma intruded into a number of narrow parallel fissures could form such a composite dyke as the one described. In this connection, he drew attention to certain lodes in Cornwall which consist of a number of quartz-veins separated one from the other by narrow layers of highly metamorphosed country-rock, which there is killas. A section of one of these lodes had similarities to the section shown of the composite dyke, the quartz and killas of the lode being represented by quartz-porphyry and dolerite respectively, in the dyke. If the chemical compositions of the basalt and the dolerite were alike, or nearly alike, it would be a coincidence not without significance, and he would be glad of information from the Authors on this interesting point.

Mr. Hawkes, replying on behalf of the Authors, said that there was some evidence that the direction of flow of the dyke magmas had a horizontal component, and it was suggested that the movement was from north to south. It was not believed that the flow was solely a lateral one, as the resorption and incipient melting of the intratelluric phenocrysts of the acid rock were assigned to relief of pressure upon intrusion, thus indicating an uprise.

Some of the dolerite-xenoliths in the neighbourhood of the shattered portion of one of the basic dykes were undoubtedly derived in place, but the even thickness of the dolerite-dykes along the greater part of their outcrop was taken as an indication that the xenoliths were not derived from these dykes at the site of

their present outcrop.

No interaction between the acid magma and the xenoliths had been detected; but the rare occurrence of reaction-rims round the quartzes of the porphyry was possibly due to basification. The contention that the xenocrysts of the dolerites were derived from a phenocryst-bearing acid magma, and not from quartz-porphyry rock, was based on the absence of quartz-porphyry xenoliths from the dolerites, and the freedom of the euhedral xenocrysts from any attached acid ground-mass.

The Authors had not discussed the origin of the two magmas,

but wished to establish the fact of their co-existence.

The field and petrological relationships of the dolerites to the country-rocks did not support Dr. Jones's suggestion regarding their mode of origin.



enclosing rock, might, in consequence of exchange of constituents, have had at some period a density sufficient to enable them to sink

in the magma.

Dr. W. R. Jones congratulated the Authors on their interesting and very suggestive paper, and asked whether they thought that it was at all possible for the doleritic part of the composite dyke to have been formed by the crystallization of the basalt of the countryrock, when narrow layers of basalt became surrounded with intrusive acid magma. If that were possible, then a homogeneous acid magma intruded into a number of narrow parallel fissures could form such a composite dyke as the one described. In this connection, he drew attention to certain lodes in Cornwall which consist of a number of quartz-veins separated one from the other by narrow lavers of highly-metamorphosed country-rock, which there is killas. A section of one of these lodes had similarities to the section shown of the composite dyke, the quartz and killas of the lode being represented by quartz-porphyry and dolerite respectively, in the dyke. If the chemical compositions of the basalt and the dolerite were alike, or nearly alike, it would be a coincidence not without significance, and he would be glad of information from the Authors on this interesting point.

Mr. Hawkes, replying on behalf of the Authors, said that there was some evidence that the direction of flow of the dyke magmas had a horizontal component, and it was suggested that the movement was from north to south. It was not believed that the flow was solely a lateral one, as the resorption and incipient melting of the intratelluric phenocrysts of the acid rock were assigned to relief of pressure upon intrusion, thus indicating an uprise.

Some of the dolerite-xenoliths in the neighbourhood of the shattered portion of one of the basic dykes were undoubtedly derived in place, but the even thickness of the dolerite-dykes along the greater part of their outcrop was taken as an indication that the xenoliths were not derived from these dykes at the site of

their present outcrop.

No interaction between the acid magma and the xenoliths had been detected; but the rare occurrence of reaction-rims round the quartzes of the porphyry was possibly due to basification. The contention that the xenocrysts of the dolerites were derived from a phenocryst-bearing acid magma, and not from quartz-porphyry rock, was based on the absence of quartz-porphyry xenoliths from the dolerites, and the freedom of the euhedral xenocrysts from any attached acid ground-mass.

The Authors had not discussed the origin of the two magmas,

but wished to establish the fact of their co-existence.

The field and petrological relationships of the dolerites to the country-rocks did not support Dr. Jones's suggestion regarding their mode of origin.

11. The Geology of the Llandovery District: Part I.—The Southern Area. By Owen Thomas Jones, M.A., D.Sc., F.G.S., Professor of Geology in the Victoria University of Manchester. (Read March 11th, 1925.)

[PLATE XXI-MAP.]

CONTENTS.

		rage
1.	Introduction	344
IT.	Historical Review	346
III.	Stratigraphical Details	349
IV.	Summary of the Geological History of the District	376
	Appendix I. Localities mentioned in 'The Silurian System'	383
	Appendix II. Fossil Localities represented by Fossils in the Museum of Practical Geology, London	385
	Appendix III. Fossils in the Sedgwick Museum, Cambridge	

I. Introduction.

NEAR the small market-town of Llandovery, in the Towy Valley, the main river flowing southwards from the direction of Rhandirmwyn is joined by two important tributaries. East of the town the River Gwydderig enters from the east, and joins the Brân which flows south-westwards along a strike-valley from the direction of the Sugar Loaf, between Llandovery and Llanwrtyd Wells. The town lies on an alluvial flat between the Towy and the Bran, which enters the main river about a mile below. It is served jointly by the Great Western and the London, Midland, & Scottish Railways. From the Sugar Loaf to Llandovery the railway skirts the valley of the Bran, and below the town it continues in the same direction along the broad floor of the Towy towards Llandeilo. Carmarthen, and Swansea. Between Llandovery and Llangadock. 6 miles below, there is a main road on each side of the valley, that on the north side being the more frequented. The district is included in the 1-inch Geological Survey map, Sheets 41 & 42 N.W. (Old Series); in the 1-inch Ordnance Survey map, Sheets 212, 213, & 196, and in the 6-inch sheets, Carmarthenshire 10 S.E., 11 S.W., 18, 19 N.W., 26 S.E., 27 N.W. & S.W.

The rocks near the town belong to the upper part of the Bala formation, but at the Sugar Loaf, 7 miles away to the north-east, a lower part of that formation, including the *Dicranograptus*-Shales, is rolled up in the core of a faulted anticline. The rocks that were assigned to the Llandovery formation by Sir Roderick Murchison lie east of the Towy-Brân valley, their dip being in general at high angles towards the south-east. It is now known

that rocks of the same age occur 5 or 6 miles away on the opposite side of the valley, and that, despite minor undulations, their prevailing dip is north-westward. The axis of folding which I have previously named the Towy Anticline 1 is situated between these two tracts of Llandovery rocks, and appears to range north-eastwards from Llandovery along the Brân valley to the Sugar Loaf. Some miles farther in that direction the volcanic rocks of Llanwrtyd Wells, which lie near the base of the *Dicranograptus* Shales,

erop out along the same anticlinal axis.2

About 4 miles away to the south-east of the town a range of hills forming the south-western continuation of Mynydd Eppynt, near Builth, strikes nearly parallel to the Brân-Towy valley, and reaches in places an elevation of over 1400 feet. On it lie Mynydd Bwlch-y-Groes and Mynydd Myddfai, separated by the deep through-valley of the Gwydderig, which cuts the range transversely and carries the main road from Llandovery to Brecon. The junction between the Silurian and the Old Red Sandstone lies near the crest of the range, from Mynydd Bwlch-y-Groes to Trichrûg, near Llandeilo. The tract between Mynydd Bwlch-y-Groes and the Towy valley is formed of short ridges, the dominant trend of which is from north-east to south-west.

Between the narrow strip of Bala rocks bordering the Towy valley and the Wenlock-Ludlow formation, which occupies the main range and its slopes, lie the Llandovery rocks. The tract which they occupy extends for a distance of about 10 miles from north-east to south-west, and is divisible broadly into two areas, which may be distinguished as the Southern Area and the Northern Area respectively. The stratigraphical succession is relatively complete in the middle regions of these areas, but in each area the formation becomes greatly attenuated (or may even disappear) both north and south.

The limits of the southern area may be seen by reference to the map (Pl. XXI). South of it lies the Llangadock district, which

is being investigated by Dr. T. T. Groom.

The stratigraphical succession and the relations of the rockgroups to one another have been examined in greater detail in the southern area. The mapping of the northern area and the collecting of fossils therein have, however, been sufficiently advanced to show that the general succession established in the south of the district can be recognized farther north, and that the faunas of the corresponding groups are (on the whole) similar. On the other hand, certain changes of lithology make their appearance northwards from Llandovery, and introduce fresh problems, besides adding to the difficulties of mapping the boundary-lines between the various groups. These problems, although having an interest

¹ O. T. Jones, 'The Geological Structure of Central Wales' Q. J. G. S. vol. lxviii (1912) pp. 339, 341.

² L. D. Stamp & S. W. Wooldridge, 'The Igneous & Associated Rocks of Llanwrtyd (Brecon)' Q. J. G. S. vol. lxxix (1923) pp. 16-46.

of their own, are regarded as of subsidiary importance, in comparison with that of determining the succession and mutual relations of the strata in the Llandovery rocks of the type-area. The completion of the investigation will necessitate spending more time in the northern area. I venture to submit to the Society the results which have been obtained by a detailed investigation of the southern area, and to express the hope that the results will be found of sufficient interest to justify me in bringing them forward at this stage. Since, however, the northern area has yielded some important evidence regarding the age of some of the rock-groups, which could not be obtained farther south, I have made use of such evidence in the present communication.

The prolonged closure of the Museum of Practical Geology renders it impossible at present to deal adequately with the fauna of the formation, so that this communication relates mainly to the stratigraphy and tectonics of the area, and only such palæontological matters are introduced as are necessary to the main purpose.

II. HISTORICAL REVIEW.

A full account of the origin of the nomenclature of the Llandovery Series has appeared in a previous volume of this Journal, so that it is only necessary to refer here to some aspects not dealt

with in that communication.

Sir Roderick Murchison, in the second part of the 'Silurian System', described and figured numerous fossils collected by him and others in various parts of the district. As so many of these fossils are types, it may serve a useful purpose to furnish (see Appendices, pp. 383-89) some notes on the localities and horizons in the Llandovery district as a whole, from which fossils have been obtained by previous collectors. Murchison refers very briefly to the southern area, and he gives no stratigraphical details. The structure of the northern area, especially around Noeth Grûg and Cefn-y-gareg is, however, somewhat fully described and illustrated by a section drawn from Llanfair-ar-y-Bryn to Castell-Craig-Gwyddon, but there is little information regarding the characters of the rocks.

The district was mapped by the Geological Survey about 1843, and some years later (about 1855) it was re-examined by W. T. Aveline, who recognized three distinct rock-groups below the base of the Wenlock formation, namely:—(a) Green shales, and (b, c) two superposed groups of sandstones, each containing species of **Pentamerus**. An attempt was made to separate off the lower group of sandstones from the underlying rocks: this was more or less successfully accomplished in a part of the southern area; but it apparently proved impossible elsewhere, and the attempt was abandoned. The upper sandstone group was, however, found to overstep the lower, as if there were a pronounced unconformity at its base. This upper group and the overlying

¹ 'The Valentian Series' Q. J. G. S. vol. lxxvii (1921) pp. 144-74.

green shales were separately mapped, and the letter b^4 was inserted in the map where the lower group was believed to occur. The examination by J. W. Salter of the fossils collected in the district confirmed the accuracy of Aveline's observations. These investigations formed the basis for the designation by Murchison of the Llandovery rocks as a distinct formation. The lower group, or Lower Llandovery, as it was thereafter called, was assigned in the legend of the Geological Survey map to the Lower Silurian, and the Upper Llandovery (together with the green shales, afterwards named 'Tarannon Shales') was grouped with the Upper Silurian.

Sir Andrew Ramsay makes brief references to the district in 'The Geology of North Wales'. In the 1st edition (1866) the rocks between the Wenlock and the Bala formations are divided (p. 2) into Tarannon Shales, Upper Llandovery, and Lower Llandovery, the first-named being apparently included with the Wenlock and the latter bracketed together (as the 'Llandovery rocks, Intermediate Series'), although a physical break is indicated between them, and he refers (p. 5) to the rapid overstep of the Upper over the Lower Llandovery. In the 2nd edition (1881) the Lower Llandovery was included with the Lower Silurian, while the Upper Llandovery rocks were considered (p. 18) to form the basement-beds of the Upper Silurian; the importance of the physical break between these two groups was again emphasized. In the 'Catalogue of Cambrian & Silurian Fossils in the Museum of Practical Geology', the fossils from various localities in the district are assigned to the Lower or to the Upper Llandovery. There are, however, several errors in that Catalogue; some wellknown Upper Llandovery localities are referred to the Lower Llandovery, while some Lower Llandovery localities occur under the heading of 'Caradoc', and even of 'Upper Llandeilo'. Notes on the localities which have yielded the fossils preserved in the Museum of Practical Geology are given in Appendix II (p. 385).

J. W. Salter & T. McKenny Hughes attempted, from their personal knowledge of the district, to distribute the fossils in the Sedgwick Museum among the Lower and Upper Llandovery subdivisions; some of the localities are, however, wrongly assigned (see Appendix III, p. 387).

Sedgwick ² gives (op. cit. pp. 482–86) lists of fossils collected from various quarries in the district, but it is difficult to identify

with certainty some of these quarries.

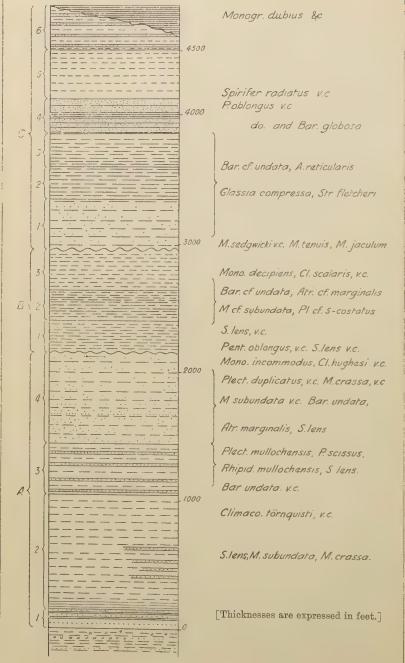
In a former communication to this Society ³ I gave a brief description of the succession, and divided the Llandovery into Upper and Lower, each being subdivided on lithological grounds into two groups. It was suggested that a comparison with the Haverfordwest development seemed to indicate the existence of a

¹ 'Siluria' 4th ed. (1867) p. 85.

² 'On the May Hill Sandstone & the Palæozoic System of England' Phil. Mag. ser. 4, vol. viii (1854) pp. 301, 359, 472.

³ 'The Valentian Series' Q. J. G. S. vol. lxxvii (1921) pp. 163-64.

Fig. 1.—Vertical section of the Llandovery rocks in the Llandovery district (Southern Area).



physical break between the Upper and the Lower divisions. I did not then suspect that an important group intervened between these divisions, nor indeed could it have been discovered at that time, since the tract where the relations between these divisions can be clearly observed was occupied by a dense wood (Scotland Wood). During the war the trees were felled, and on my return to the district I was able to examine this area in detail. A brief account of the succession and fauna was read at the Meeting of the British Association in Toronto (August 1924).

III. STRATIGRAPHICAL DETAILS.

Near Penlan, about a mile and a quarter east of Llandovery, the higher beds of the Series occupy a well-defined ridge, which continues south-south-westwards for a distance of 4 miles to the River Sefin, east of Llangadock. The ridge diminishes somewhat in altitude southwards, and, although it is almost continuous, the rocks that form its summit belong to successively lower horizons in that direction. East of the Penlan ridge the ground falls away gently at the northern end, and steeply at the southern end, towards the outcrop of the Wenlock rocks. Beginning near the town, another ridge rises sharply from the Towy valley, and extends past Cefn Rhuddan nearly parallel to the former for $2\frac{1}{2}$ miles. Between these two ridges is a belt of lower ground of varying width. within which the rocks are partly obscured by Boulder Clay. About 4 miles south of Llandovery a prominent escarpment rises abruptly from the main road on the east side of the Towy valley, and ranges nearly due east and west towards Cilgwyn House on the River Ydw. Between the Cilgwyn escarpment and the Cefn-Rhuddan ridge the rocks over wide areas are concealed by Boulder Clay.

The investigation of the district has shown that the former classification of the Llandovery into an Upper and a Lower division is incomplete, and I have been led to adopt instead a threefold subdivision. In order not to burden geological nomenclature with fresh names, I propose to refer to these Divisions or Stages as (A) Lower, (B) Middle, and (C) Upper Llandovery, smaller subdivisions or Groups being indicated by numbers: for example, A₄, B₂. This course involves occasionally somewhat cumbrous descriptions, which would have been avoided by the use of local

names.

It appears from comparison of my maps with the published 1-inch map that the boundaries of the Upper Llandovery compare closely with the results of my own mapping, but that the Middle Llandovery was formerly included in the Lower Llandovery Series. On the other hand, certain strata (mainly barren) near the base, which were, in places, excluded from the Llandovery must be assigned to that series. The classification of the Llandovery Series which I have adopted is, therefore, as follows (see also fig. 1):—

			Thickness in	feet.
WENLOCK SERIES.			Dark-grey, finely laminated shales, passing up into rubbly mudstones with thin grit-bands	(?)
		(6)	The Green Micaceous Group. Greenish shales, with thin bands of micaceous sandstone; only important in the Northern Area.	(?)
		(5)	The Pale Mudstone Group. Soft	
	Upper Llan- dovery	(4)	greenish-blue mudstones The Sandstone Group. Dark-grey sandstones, with thin bands of	380
	Stage (C). (1570 feet + .)	(3)	shale	270
			Pale greenish mudstones passing up into a shale-band	270
LLANDOVERY SERIES.		` ′	The Lower Greenish Mudstone Group. Similar to 3	250
		(1)	Calcareous Nodule Group. Hard greenish mudstones, with calcareous nodules	400
		(3)	Unconformity. The Hard Mudstone Group. Hard	
	Middle Llan-	(2)	greenish mudstones	300
	dovery Stage (B). (800 feet.)		ceous mudstones, poorly exposed: thickness uncertain, about	250
		(1)	Calcareous Nodule Group. Hard greenish mudstones, with small calcareous nodules	250
		(4)	Unconformity. Sandy Mudstone Group. Tough sandy mudstones, with thin bands of	
		(3)	sandstones	700
	dovery Stage (A). (2350 feet.)		sandy mudstones, with thin bands of fossiliferous micaceous sand- stones	400
		(2)	Mudstone Group. Greenish - blue shaly mudstones without hard bands, passing down into the under-	
		(1)	lying group: thickness from 1100 to Basement-beds consisting of dark-	1200
			blue shales, with thin bands of grey sandstone, overlying grey quartz- itic sandstones and occasional thin conglomerates; development and thickness variable, ranging from	
BALA SERIES.	Upper Bala Stage.		50 to Dark-grey shaly mudstones, passing upwards into shales interbedded with thin laminated sandstones, and an occasional pebbly seam or thin	100
			band of conglomerate	(1)

The Bala Series.

The Bala rocks are well exposed in the upper part of the prominent escarpment between Cilgwyn House and the main road to Llangadock; also in occasional sections due south of Cilgwyn, as at Nelson Cottage, Blaen-y-cwm, east of Letty'rhyddod, and

in the Sefin valley.

The lowest beds that have been examined consist of grey or brownish-grey sandy mudstones, in places slightly calcareous. They yielded Pleetambonites ef. papillosus, etc., north of Nelson Cottage (where they dip northwards at 35°), and Christiania tenuicinta, etc., in the lane 100 yards west of Blaen-y-ewm House (where they dip east-south-eastwards at 80°). Near the reservoir, 180 yards east of the house, a dark-blue sandy mudstone was formerly quarried, and in the cart-road a few yards east of the quarry the lowest beds of the Llandovery Series crop out. The stratigraphical relations of the two formations are not clear, and there is nothing in them to indicate whether the rock in the quarry should be assigned to the Bala or to the base of the Llandovery formation. It is not quite like any other in the district. but is more reminiscent of Bala than of Llandovery deposits. The only fossils that I found were Leptana rhomboidalis and Meristina crassa, and they do not afford much assistance. In the Museum of Practical Geology (London) there is, however, a large collection of fossils made many years ago and labelled Blaen-y-cwm, Llandeilo, and it seemed as if they must have been obtained from this quarry. Although not much rock is visible at present, what there is appears to be so barren that it seemed difficult to understand how so large and varied a collection could have been obtained therefrom. J. W. Salter 1 states, however, in regard to one of the recorded fossils, Lituites undosus, that 'we do not know of more than one locality for it in the quarry close to Mr. Rogers's cottage at Blaen-v-cwm'. Mr. Rogers died in 1923 at a very advanced age, and was living at Blaen-v-own when the fossils were collected. This description clearly, therefore, applies to the above-mentioned quarry. The fossils are arranged in the cases assigned to the Llandovery Series, but they include at least two species that have never been found hitherto in undoubted Llandovery rocks: namely, Phacops (Chasmops) conicophthalmus and *Plectambonites ruralis*. The whole of this collection may be assigned with some confidence to the Bala, although the record of Atrypa reticularis from the same locality raises a doubt whether fossils from higher horizons were not referred to the same place.

The upper beds of the Bala Series include numerous thin bands of finely laminated sandstone, also grey sandstone in thicker beds and irregular masses with a nodular appearance. A good section

¹ Palæontological Appendix to J. Phillips, 'The Malvern Hills compared with the Palæozoic Districts of Abberley, &c.' Mem. Geol. Surv. vol. ii (1848) p. 353.

can be examined on the steep slope above Cilgwyn House, and is as follows:—

Thickness in f	eet.
Sandstone and shale in thin beds; some beds weather with a bronzy	
lustre, others are purplish because of manganese staining 40 to	50
Gap near path; including some 6 feet of mudstones and 'nodular' grits,	
about	40
Shales, as above, with similar weathering and staining; including 2-inch	
to 3-inch bands of finely laminated grey sandstone and a 2-foot band	
at the base	16
Blue-grey micaceous mudstones, seen to about	20

This section illustrates the general character of the Upper Bala rocks of the district, but individual beds vary somewhat rapidly when traced along the strike. Near the flat-topped space at the edge of the escarpment (known as The Terrace or The Platform) the mudstones are pebbly, and contain fragmentary fossils, among which abound crinoid-ossicles; brachiopods (including Dalmanella sp.), trilobite-fragments, and Favosites sp. can also be recognized. South of Blaen-y-cwm a coarse pebbly grit strikes parallel to the Llandovery rocks, and makes a narrow ridge. From its position I assumed at one time that this bed formed the base of the Silurian, but some débris thrown out from rabbit-holes prove that it is overlain by grey rubbly mudstones, which present the lithological characters of the Bala beds; while a few yards away to the east is a small outcrop of smooth blue shale similar to that which occurs generally near the base of the Llandovery Series. A very marked lithological change takes place between these two exposures. Moreover, the pebbly bed is similar to others which occur not far below the top of the Bala, near The Terrace above Cilgwyn. At a distance of about 600 yards south of Blaen-v-cwm, the conglomerate yielded Plectumbonites ruralis, thus confirming its identification as belonging to the Bala Series.

In the Northern Area the higher beds of the Bala Series have proved to be, in places, very fossiliferous, but it is only necessary to refer to a few localities. A small quarry by the side of the stream, a quarter of a mile north-north-east of Esgair-fwyog. $2\frac{1}{2}$ miles east of Cynghordy Station, yielded *Plectambonites* ruralis in some abundance, associated with Atrypa marginalis, Plectambonites scissus, and others. Another locality is on the road north of Scrach, 2½ miles east of Llanfair-ar-y-Bryn church, where Plectambonites ef. papillosus, P. sp. nov. (a typical Upper Bala species), Christiania tenuicineta, Cyclopyge, Trinucleus, and a variety of other forms were found in a decomposed calcareous grit lying only a few yards below the base of the Llandovery. The third locality is a small quarry south of Scrach, where some of the above-mentioned forms and Orthograptus truncatus all occurred in a calcareous nodule. The remaining fossils have not been identified, but those enumerated above are sufficient to demonstrate the Bala age of the sediments in which they occur.

The Lower Llandovery Stage (A):

(A1) The Basement Group.—Near the Llangadock road, immediately beyond the third milestone from Llandovery, there are old quarries in a fine-grained, grey, well-bedded sandstone which dips east 10°-15° south at 35° to 43°, and forms the crest of the steep slope that overlooks the road. A few yards below its base are many exposures of dark-blue mudstones, with thin bands of grey laminated sandstone and sandy micaceous seams. contrast with the steady dip of the rocks in the quarries, the underlying beds are traversed by minor folds with a strong north-eastward pitch. Towards the upper part of the Basement Group the sandstone-beds are thinner, and are interleaved with dark-blue smooth shales, occasionally breaking into long narrow prisms. In the quarry nearest the main road undulating dark laming can be seen on the fractured surfaces of some of the beds; such beds usually are strongly rippled. The succession is interrupted by a fault which passes a few yards east of the quarries, and ranges northnorth-eastwards through a deep notch in the ridge. Beyond the fault similar sandstones dipping a few degrees north of east are exposed near the crest of a second ridge running nearly parallel to the first. From here the outcrop of the sandstones can be traced in an easterly direction towards Cilgwyn: it is, however, interrupted by several faults ranging nearly due north and south, which, although they are almost parallel to the general strike of the Llandovery district, behave as dip-faults. Blue sandy mudstones with thin laminated layers are visible at intervals below the base of the sandstones. On Pentirbach, half a mile west of Cilgwyn, the sandstones dipping northwards at 34° are overlain in a small quarry by smooth micaceous shales, similar to those in the quarries near the Llangadock road. About 100 yards east of this exposure the beds are cut off by a fault; but, 170 vards south, similar shales overlie a sandstone, the upper part of which contains large pebbles. Another 100 yards away to the east smooth, flaggy, ironstained shales rest upon a vellowish conglomerate and coarse pebbly sandstone. It appears, therefore, as if the grey sandstone of the western end of the ridge has passed into a conglomeratic rock within a distance of less than three-quarters of a mile. In an old quarry, a short distance east of The Terrace above Cilgwyn, there is another exposure of similar beds, where the following section is visible:-

Thickness in	feet	inches.
Smooth, blue, rusty-weathering shales in very thin beds, and in-		
cluding some thin irregular bands of grey sandstone, seen		
to about	6	()
Fine-grained grey sandstone, with a wayboard of shale at the		
	0	8
Fine-grained sandstone, with occasional pebbles	0	6
Irregular band of shaly mudstone, with some pebbles in its base,		
resting on a smooth surface of coarse pebbly sandstone;		
thickness=zero to	0	4.
Grey, medium-grained, felspathic sandstone; upper 6 inches		
pebbly	1	9

Apparently a thickness of about 6 to 8 feet of rock had been worked below the strata enumerated above, but this part of the quarry is now overgrown. There is a gradual transition upwards from the pebbly sandstone into an alternating series of fine-grained sandstones and smooth blue shales, and, although the pebbly beds are similar in appearance to those in the Bala Series, they cannot be dissociated from the shales, which are of Llandovery aspect.

In the small stream 300 yards east-north-east of Cilgwyn House, shales of the same character overlie grey sandstone, and pass up rapidly into thickly-bedded blue mudstones showing a coarsely nodular structure. Mudstones similar to these are exposed also in a road-cutting west of the stream 300 yards above the house, but appear to lie at a greater vertical distance above the top of the arenaceous beds; these nodular mudstones form part of the overlying group (A_2) . There are no good exposures farther south between Cilgwyn and the River Sefin, although some ironstained smooth shales associated with thin bands of grey sandstone crop out in the cart-road immediately east of Blaen-y-cwm Quarry, and are assumed to represent the Basement Group. In the northern bank of the Sefin valley, rubbly grey speckled mudstones (similar to beds which have elsewhere vielded Bala fossils) are succeeded eastwards by a narrow band of smooth blue shale and micaceous shales, which contain near the top a 6-inch band of quartzitic sandstone. These are considered to be the Basement Beds, and, a little higher in the succession, typical Lower Llandovery fossils All the beds in this section are inverted, and dip northwestwards at 70°.

Base of the Lower Llandovery.—On the evidence which can be obtained in the Llandovery district alone, it is impossible to indicate exactly where the boundary between the Llandoverv and the Bala should be drawn. In drawing the line at the base of the sandstones or conglomerates described above, I have been influenced by the strong similarity between this part of the succession at Llandovery and that in the Narberth-Haverfordwest district,1 where Basement-Beds consisting of conglomerate or grev sandstone, overlain by smooth, dark-blue, ironstained shales, pass up into the blue mudstones of the Cartlett Beds, in which latter a coarse nodular structure is characteristic of certain horizons near the base. It is difficult, however, to draw any real distinction between the thinly-bedded grey sandstones which occur in the upper part of the Bala Series and the somewhat thicker sandstones which have been assigned to the Llandovery formation, and even the conditions that gave rise to the pebbly beds of the Llandovery are foreshadowed before the close of Bala time. I attach greater importance in distinguishing between the two formations to the change which takes place at the boundary in the character of the argillaceous sediments. In the upper part of the Bala Series these

¹ 'The Geology of the South Wales Coalfield, Pt. xi: The Country around Haverfordwest' Mem. Geol. Surv. 1914, pp. 77 et seqq. & fig. 12, p. 81.

are grey, rubbly, ill-bedded mudstones, frequently speckled or blotched with paler patches; while at the base of the Llandovery we find smooth well-bedded shales, often finely laminated, and exhibiting a strong tendency to rusty weathering, especially along joints. I have found a change of this kind to be of universal occurrence at the base of the Silurian, whether the rocks belong to the shelly or to the graptolitic facies. The evidence based on lithology is confirmed by the change in the fauna which takes place at the boundary; several well-known fossils of the Bala rocks do not ascend above this level. Despite the fact that there is complete conformity between the two formations and that it is difficult to indicate precisely where the boundary should be drawn, there appears to be, nevertheless, a palæontological break between them.

(A2) The Mudstone Group.—The Basement-Beds, which form the summit of the Cilgwyn escarpment, and dip in a general northerly direction, are succeeded northwards by a group of greenish-grev or olive-green mudstones. Near the base these exhibit a rapid transition in lithology to the underlying dark shales of the Basement-Beds; while at a slightly higher level mudstones in thick beds, with an ill-defined nodular structure and a tendency to weather in large ovoids, form a characteristic type. So far as is known, the latter are confined to the lower part of the group. Higher beds are exposed near Blaendynfych, north of Cilgwyn, and in the lane between that place and Cerig-cwnwd, and again farther north near Ty'n-y-coed. Near Blaendynfych the olive-green mudstones contain narrow, straight, or curved limonitic streaks of unknown origin; precisely similar rocks occur in the Cartlett Beds of the Haverfordwest district. Upwards the beds become harder, and at the top the incoming of thin bands of laminated grey sandstone marks the passage into the overlying group (A_3) .

Farther north, this group is exposed at intervals along the byeroad to Cilgwyn, which leaves the main Llangadock road about a mile south of Llandovery. Near the main road the mudstones strike north-eastwards with a vertical dip. It is possible that they are not far above the base of the formation, since they contain one band of greenish-grey sandstone a few inches thick, similar to those in the Basement-Beds. Pale-grey mudstones typical of the group are exposed near the cottage on the south, and at intervals along the Cilgwyn road. About 400 yards south of the cottage, they pass gradually into the overlying group. A similar transition can be observed a quarter of a mile east of the cottage, along the cart-road to Cefn Rhuddan, where the beds are inverted and

dip north-westwards at 70°.

North of Cilgwyn only a few fossils have been obtained, namely:—Stricklandinia lens on the Cefn Rhuddan cart-road about 150 feet below the top of the group, and Plectambonites scissus together with Dalmanella sp. in the lane east of Blaendynfych, where the beds dip north 10° east at 26°.

Near Blaen-y-cwm there is an altogether different development, which can be examined on the ridge a quarter of a mile east of Lletty'rhyddod, and on the steep slope leading down from that ridge into the valley on the east. The Basement-Beds are exposed on the western bank of a strike-hollow, which intervenes between that ridge and a parallel ridge formed by the conglomerate in the Bala rocks. The ridge is made up of greenish mudstones interbedded with numerous bands of grey, laminated, quartzitic sandstone, often exhibiting a well-defined prismatic jointing. These beds dip east 18°-32° south at about 60°; southwards they assume a vertical attitude, or are slightly overturned, and the strike is nearly south-west; but northwards they dip due east at 40° to 50°. These beds, although not unlike certain parts of the overlying group (A₃), are considered to be a local development of the Mudstone Group (A₂), because the sandstone-bands become thinner as the group is traced northwards. On Lan-y-Cilgwyn, threequarters of a mile north, the bands of sandstone are not only thinner, but also relatively less numerous, and in about the same distance farther north the strata on their line of strike contain merely a few very thin layers of quartzitic sandstone, while beyond that point hard bands are absent. In the opposite direction the sandstones practically replace the mudstones, so that in the Sefin valley the group consists almost entirely of sandstones. lithology of this local development differs from that of the overlying group (A_3) in several respects. The sandstones are harder, more quartzitic, more sharply differentiated from the adjoining mudstones, and their prismatic jointing is much more conspicuous. Again, these sandstones are separated east of Blaen-y-cwm from the overlying group (A₃) by mudstones devoid of hard bands.

On the steep slope due east of Lletty'rhyddod, many fossils preserved in a limonitic material were collected from some of the harder bands of sandstone. They include Atrypa marginalis, Meristina subundata (?), Plectambonites mullochensis var., and

Dalmanella sp.

Farther south Meristina crassa was obtained from the same strata, and at a lower horizon Plectambonites scissus and P. tri-

costatus were found.

One other section remains to be described. Some 200 yards below the Victoria Arms, on the road from Llandovery to Myddfai, and about half a mile from the town, occurs an exposure of bluegrey micaceous mudstones with dark-brown manganese staining. The beds strike north-eastwards with a vertical dip, and from their lithology may probably be assigned to the Bala Series. In a stream east of the road, about 300 yards south of the Victoria Arms, there is an almost continuous section of micaceous flaggy and shaly mudstones, different in appearance from the above, and passing up into blue striped mudstones which break into spindleshaped pieces and have a marked rusty weathering. These beds are not quite like any of the lithological types that occur in the

Mudstone Group farther south, but they bear a general resemblance to certain of them. In the Northern Area very similar mudstones have yielded typical Lower Llandovery shelly fossils. On these grounds alone they must be assigned to the Lower Llandovery and most appropriately to the Mudstone Group (A_2) , because of the absence of sandstone bands. Fortunately, an exposure in the stream nearly opposite Coldbrook Cottages, 500 yards south of the Victoria Arms, yielded many specimens of Climacograptus törnquisti, preserved in full relief. The occurrence of this well-known graptolite dispels any doubt as to the age of these mudstones.

On reviewing the foregoing account of the Mudstone Group, it appears as if a progressive change in its lithology takes place from north to south. The sandstones which occur at the southern end of the district die out, and are replaced by barren greenish-grey mudstones; these in turn become darker and more shally northwards, and concurrently with this change a graptolite fauna makes its appearance.

(A3) Mudstone and Sandstone Group.—This group is exposed in Glan Towy Wood, along the road from Llandovery to Cilgwyn. At the base sandstones from 1 to 2 inches thick make their appearance among blue micaceous mudstones, similar to those of the underlying group, and become relatively more numerous and thicker as the succession is ascended. Many of these consist of moderately coarse quartz-grains associated with abundant white mica; not infrequently they seem to have been calcareous, and are now decalcified to brown sandy rottenstones. It is in such bands that fossils usually appear. At rare intervals lenticles of ferruginous sandy rottenstone of greater thickness than the ordinary sandstones occur, and are crowded with fossils. One such (which was almost made up of a variety of Orthis calligramma, preserved as casts in an ironstained coarse sand) was found near the Cilgwyn road, on the south side of a gully due west of Cefn Rhuddan. This fossil was associated with Plectambonites scissus and P. sp. nov.—an early form of P. duplicatus. Another rottenstone-band near the top of the group, about 150 vards farther up the road, yielded Stricklandinia lens in abundance. There is a less continuous section along the cart-road to Cefn Rhuddan, where the beds have an inverted dip north-westwards at 75°.

In the Cilgwyn district this group occupies the slopes east of the road to Llandovery and south of the road to Myddfai; it is well exposed near Goleugoed (pron. Goleigod). From here it crosses the two roads, and ranges a little west of north towards Glan Towy Wood. In this area the strata are affected by many undulations which have a pronounced pitch to the north-north-east. The beds have been quarried for many years by the side of the Myddfai road, three-quarters of a mile north of Cilgwyn, where they dip

north-eastwards at 28°. This quarry has been variously known as Cwar Goleugoed, Cwar-mawr, and Cwar-mawr Cilgwyn, and many fossils were obtained from it by former collectors. Fossils can be obtained with diligent search from most exposures of the group, but they are nowhere abundant. The species that occur most commonly are: -Stricklandinia lens, Meristina subundata, M. crassa, Plectambonites scissus, P. tricostatus, P. cf. mullochensis, Barrandella undata, and Atrypa marginalis; the first-named species is by far the most abundant. A well-marked variety of Orthis calligramma was seen in several localities, mainly near the base of the group, and other forms which have not been sufficiently investigated occur sporadically. A small exposure due west of Cwar-mawr, on the ridge between that quarry and the Llandovery road, yielded in abundance Orthis (Schizophorella) mullochensis and O. (Sch.) reversa in association with some of the above; these beds are about 150 feet above the base of the group. The same forms were collected also on the old road, 500 vards east-south-east of Goleugoed farmhouse. A large collection was obtained on the slope 550 yards east by south of Blaen-y-cwm, from beds which are near the junction between this and the underlying group (A_2) . The commonest form is *Plectambonites* sp. nov. (allied to P. quinquecostatus), and is associated with P. sp. nov. (early form of P. duplicatus), P. mullochensis var., Meristina subundata, Atrypa marginalis, and a narrow form of Climacograptus normalis. The first-named form occurs in the Northern Area near the base of the Mudstone and Sandstone Group (A₃), and has been found also at a corresponding level in other districts (Garth and Haverfordwest).

South-east of Llandovery this group succeeds mudstones devoid of hard bands (As) near Cefn-yr-Allt; the beds strike north-east, and have yielded some of the usual fossils in scattered exposures. The slope south of Cefn-yr-Allt descends steeply to a narrow tract of low-lying ground, the western edge of which ranges towards Coldbrook Cottages (previously mentioned). The rocks underlying this tract are concealed beneath Boulder Clay, but the edge of the strip of ground crosses the strike of the Lower Llandovery rocks at a small angle, and near the cottages the base of the Mudstone and Sandstone Group (A₃) runs into it. The beds on the Cefn-yr-Allt slope strike towards the road south of the cottages; but the section exposed in the roadside reveals rocks of a different lithology. They are blue-grey, thinly-bedded, sandy mudstones, which clearly belong to another group. There is, in fact, no room for the Mudstone and Sandstone Group (A3) at this locality between the Climacograptus-törnquisti beds and these problematical mudstones. The latter yielded Scenidium sp. and Climacograptus sp., and I believe that they belong to a higher stage (B) of the Llandovery, which, in the interval between the road north of Cefn Rhuddan Quarry and Coldbrook Cottages, has gradually overstepped some of the Lower Llandovery rocks.

(A₄) Sandy Mudstone Group.—This is the group from which many of the characteristic fossils of the Llandovery Series were obtained by previous collectors. It consists of very tough grey rocks presenting the appearance and fracture of mudstones, but containing so much sandy matter mixed with the argillaceous material that they might be regarded as muddy sandstones. It is a common lithological type for which no satisfactory name exists; in this communication I refer to such rocks as sandy mudstones.

The group can be examined readily along the upper part of the Cilgwyn road, near Pen-yr-Allt Cottage and in Glan Towy Wood, between that road and the Cefn Rhuddan quarry. A few years ago it was well exposed in cuttings in the cross-lane from the Cilgwyn road to the Myddfai road, and similar strata can be seen in several ridges north of that lane. The lowest beds, which are well exposed just below Pen-vr-Allt Cottage, are hard sandy mudstones containing numerous very thin micaceous seams. The higher beds include, south of the cottage, many bands of tough grey quartzitic sandstones measuring up to 3 inches in thickness, and crossed by well-defined closely-set joints, causing them to break up into polygonal prisms. Small nodules of impure calcareous sandstone now decalcified into sandy rottenstones are of common occurrence throughout the group, and it is from these that fossils can be most frequently obtained, although they are not confined to such nodules. I regard the beds in the Cefn-Rhuddan quarry, which is in the wood 360 yards due north of the farmhouse, as forming the base of the group, although no sharp line can be drawn between them and those of the upper part of the underlying group (A3). It was from this quarry that several of Murchison's figured specimens of well-known brachiopods were obtained, among them being Atrypa (Barrandella) undata, A. (Stricklandinia) lens, A. (Meristina) crassa, and Leptæna (Plectambonites) duplicata. These, together with Meristina subundata, Atrypa marginalis, Plectambonites scissus, and P. undulatus, are, in fact, the commonest fossils of the group; but they are associated, in places, with many other species which occur less abundantly. The most distinctive fossil is undoubtedly Plectambonites duplicatus, which occurs in profusion in certain beds, especially in the upper part of the group.

Rocks containing that fossil in abundance are exposed at intervals along the bottom of a straight valley (apparently a strike-valley) which cuts through Allt Goleugoed, and enters the Ydw valley from the south-south-east, nearly opposite Cwarmawr; but south of this place their characteristic fossils have not been recognized. All the exposures in that direction exhibit the lithology of the underlying group (A₃), and I believe that the Sandy Mudstone Group comes to an end about 200 yards south of the strike-valley. Again, in the opposite direction, the prominent ridge of Cefn Rhuddan, seamed as it is with rock-exposures, strikes towards the low-lying tract south of Cefn-yr-Allt, and is seen no

more. Alike with the underlying group it is apparently overstepped in that direction by the Middle Llandovery deposits.

Before dismissing these rocks, a brief reference to the Northern Area is necessary. The Basement Beds are only exposed in the extreme north of the district, but all the higher divisions can be identified on the slopes of the long deep strike-valley of the River Crychan, south-east of Llanfair-ar-y-Bryn church. The uppermost beds agree in lithology with the Sandy Mudstone Group (A4), and contain similar fossils. Such strata are exposed close to the Crychan, in a small stream which descends in a gully due east of Cefn House; but a thin band of dark-blue, micaceous, ochreous-weathering shales, lying a few feet above them, and exposed in the bed of the Crychan, yielded several specimens of graptolites, namely: —Climacograptus hughesi, Cl. medius, Cl. normalis (?), and a well-preserved species of Monograptus, also Stricklandinia lens. Realizing the importance of this find, Mr. R. C. B. Jones and I removed all the available shale from the band, and, after leaving it to weather for a few days, carried it away, and broke it up at leisure into very small pieces. The result was the discovery of some seventeen recognizable fragments of graptolites, among which the most important is the species of Monograptus. I have identified it with M. incommodus, because it has a dorsal curvature, although its thece recall, in some respects, M. sandersoni. Both these species have, however, so restricted a vertical range that the horizon of this band in relation to the well-known graptolite zones of the Valentian can be determined fairly exactly. In the Monograph of British Graptolites, M. incommodus is said to occur in the zone of M. cyphus (used probably in the extended sense). M. sandersoni is said to occur in the same zone in association with it, and to range up into the overlying zone of M. fimbriatus. In my own experience in Wales I have only found M. incommodus at the very top of the M.-acinaces Zone (there called the M.-rheidolensis Zone) in the Rheidol Gorge at Pont Erwyd (Cardiganshire), but have never found it in the overlying zone of M. cyphus (using this zone in the restricted sense). Its associates there are Climacograptus hughesi and Orthograptus mutabilis.

I have found a form exactly resembling that from the River Crychan in the railway-cutting a mile and a half east of Aberdovey, in association with *M. acinaces* and other species of that zone. I am of opinion that the horizon represented is the uppermost part of the zone of *M. acinaces*, near the junction with the overlying *M.-cyphus* Zone. If the horizon is higher than this, some other Monograptids might reasonably be expected to occur with this graptolite, although, in view of the limited number of

specimens found, that argument cannot be pressed.

A diagrammatic representation of the lithological and faunal succession of the Lower Llandovery Stage is given in fig. 1, p. 348.

¹ Q. J. G. S. vol. lxv (1909) p. 486.

The Middle Llandovery Stage (B).

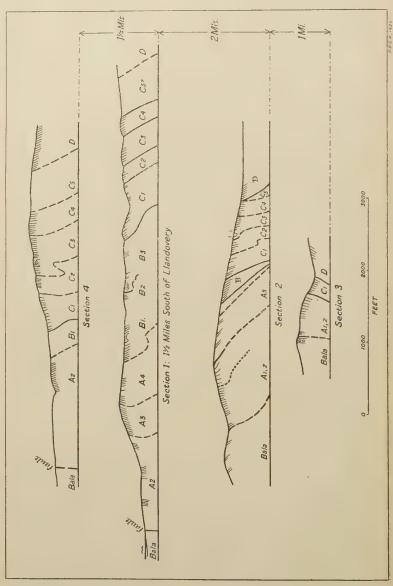
(B1) Calcareous Nodule Group.—The higher beds of the Lower Llandovery, which crop out in successive ridges in the wood west of Cefn Rhuddan, are followed eastwards by blue-grey shaly mudstones, which are conformable in strike with the underlying rocks; they contain some bands with abundant specimens of Stricklandinia lens, but apparently no other fossil. The contact between them and the Lower Llandovery is not visible, but the mudstones probably extend up to a feature at the base of the wood. Somewhat higher beds are exposed in the farmyard, and are traversed by an acute anticlinal fold, pitching north-eastwards. In the lane leading out of the yard to the east a thin band yielded a considerable variety of fossils in a poor state of preservation. Atrypa cf. marginalis, Dalmanella spp., Scenidium sp., Encrinurus punctatus, Calymene sp., and other trilobite-fragments, Petraia sp., gastropods, and crinoids may be mentioned; most of the fossils are small. The whole assemblage has a very different aspect from any in the Lower Llandovery Series, and, taking this into account, as also the difference in lithology between these sediments and those of the underlying group, one would be justified in assigning these strata to a new stratigraphical group, despite the appearance of conformity with the beds upon which

they rest.

West and south of Cefn Rhuddan strata of this character appear again to follow the uppermost group of the Lower Llandovery. In the field near a gate leading into the wood west of Coedcae, a quarter of a mile south-west of Cefn Rhuddan, there is a small crag of blue-grey mudstones with small calcareous nodules, dipping east 32° south at 50°. A few yards away to the west sandy mudstones, in a vertical position and striking south-westwards, contain Plectambonites ef. mullochensis. This fossil, taken in conjunction with the lithology of the rocks, suggests a Lower Llandovery age. There appears to be some discordance in dip and strike between the two groups at this locality, but the evidence for such a conclusion is not satisfactory. Just inside the field, at the foot of the hill on the cross-lane west of Pont Pwll-defaid, there are two small exposures of greenish-blue mudstones with small calcareous nodules, and from one of these several specimens of Stricklandinia were obtained. The beds here dip eastwards at 40°, and appear to conform, both in dip and in strike, with the sandy mudstones (A₄) exposed on the hill, which yielded Meristina crassa and Plectambonites duplicatus. A few yards away, in the ditch close to the coppice, there is a tough, compact, dark grit, which appears to be in situ; no rock like it has been seen anywhere else in the district, but its position suggests that it may be a basement-bed of the mudstone group. On the north side of the road to Llwynywormwood, near Pont Pwll-defaid, a small quarry in greenish-blue thickly-bedded mudstones, with small calcareous nodules and sandy ferruginous seams, yielded numerous

2 B 2

Fig. 2.—Sections along the lines indicated on the map (Pl. XXI), on the scale of 4 inches to the mile.



specimens of Stricklandinia lens, as also Plectambonites scissus and Calymene cf. blumenbachi; the beds dip east 10° north at 32°. About 200 yards away to the south, similar mudstones dip east 12° north at 30°, near the ruins of Gloigoed-fach. The strike of the Lower Llandovery beds on the west is in general slightly different from that of the mudstones hereabouts; but, as the exposures are some distance away, this may have no significance.

Some small exposures near a deep ditch, about 80 yards south of Gloigoed-fach, furnished, however, striking evidence, both as to the age of the mudstone group that we are considering, and as to its relation to the Lower Llandovery rocks. In the field immediately south of the ditch, some hard sandy mudstones crop out; they dip east 40° north at 28°, and must belong to some part of the Sandy Mudstone Group (A4). About 10 yards away, massive mudstones dipping due east at 40° (see fig. 3, p. 374), which are exposed in the banks of the ditch, yielded abundant specimens of both Stricklandinia lens and Pentamerus oblongus. The latter fossil proves that we are dealing with a higher stratigraphical group than the Lower Llandovery, since there is no evidence that P. oblongus has ever been found in the Lower Llandovery rocks of any district. The marked discordance in dip and strike between exposures so close together is in itself almost sufficient to demonstrate that the Mudstone Group is unconformable on the Lower Llandovery. From this locality the base of the group can be traced almost due south for over a mile to the slope above Gorllwyn-fawr, where it disappears.

An unconformity at this horizon supplies a sufficient explanation for the absence of the highest group (A_4) of the Lower Llandovery in the southern part of the district, and also accounts for the disappearance of the two higher groups $(A_3 & A_4)$ between Cefn Rhuddan and Coldbrook Cottages, which is otherwise almost impossible to explain (compare sects. 1 & 4, fig. 2).

The fossils of the Calcareous Nodule Group, with the exception of Pentamerus oblongus, are not unlike those of the Lower Llandovery, but it is probable that careful comparison will show that forms which are provisionally referred to Meristina subundata. Atrypa marginalis, and Barrandella undata are specifically or varietally different from similarly-named Lower Llandovery forms. That they differ in some respects is certain, but the diagnostic value of the differences must be a subject for further study. A noteworthy feature of the group is the abundance of Stricklandinia lens, and the prevalence of trilobites of the genera Calymene, Lichas, Phacops, and Encrinurus.

These beds were assigned by Aveline to the Lower Llandovery Series, but the existence of an unconformity, which brings about the disappearance by overstep of more than 1000 feet of Lower Llandovery rocks in a distance of less than a mile, clearly makes it necessary to assign these mudstones and others now to be

described to a new stage within the Llandovery Series.

- (B2) Shaly Mudstone Group.—This group is poorly exposed, and has yielded very few fossils. In the lane south-east of Cefn Rhuddan there are some exposures of blue, shaly, micaceous mudstones, which are affected by small-scale folding; farther south the beds near the top of the group are shaly rusty-weathering mudstones, the outcrop of which is indicated by a slight depression. A similar depression occurs near the base, and use has been made of these depressions in mapping the limits of the group. Fossils were obtained on the northern bank of the River Idw, 200 yards above Pont Pwll-defaid; they include Stricklandinia lens, Dalmanella sp., and Plectambonites sp. nov. (allied to quinquecostatus). Most of these occur also in the overlying group (see below). Meristina cf. subundata, Barrandella cf. undata, and Atrypa cf. marginalis were obtained in a small quarry, nearly half a mile south of the River Ydw, in beds which are near the top of the group, if they are not actually at the base of the overlying group. In a lane and a small quarry, about half a mile north-east of Cefn Rhuddan, there is a considerable thickness of soft olive-green mudstones, which probably belong to the group; but, as they yielded no fossils, their age cannot be determined.
- (B₃) Hard Mudstone Group.—This group also is poorly exposed, but it has yielded most of the fossils that have been obtained from the Middle Llandovery stage. In the valley of the Ydw, east of Pantygaseg, there are several quarries in hard, bluish-green, calcarcous mudstones, occasionally containing small quartz-pebbles or quartz-grains, which stand out conspicuously on a fractured surface. Some of the beds have a rude concretionary structure, and large calcarcous nodules are abundant at certain horizons. Stricklandinia lens is very common in some of these exposures, and usually was the only fossil found.

The greater number of the fossils were collected at three localities near the Ydw valley. The first of these is the yard of Pantygaseg Farm, where a thin sandy band near the base of the group yielded Barrandella ef. undata, Stricklandinia lens, Leptæna rhomboidalis, Plectambonites scissus, P. sp. nov. a, P. sp. nov. β (allied to quinquecostatus), together with forms of Atrypa, Dalmanella, Dietyonema, and Favosites not yet

specifically identified.

At the second locality, which is near a footbridge on the River Ydw, some of the forms already enumerated were found, together with Meristina subundata, Atrypa marginalis, and Encrinurus

punctatus.

A greater variety of forms was collected in a small quarry by the roadside, due south of the last locality. Many of these specimens appear to be of undescribed species, so that in such cases only a generic determination can be given at present; they include:—

Atrypa sp., Barrandella cf. undata, A. cf. marginalis (or sp. nov.), Triplecia insularis, Stricklandinia lens, Plectambonites

undulatus, P. sp. nov. β (allied to quinquecostatus), Orthis sp., Hebertella lata (J. de C. Sowerby), Lingula, Scenidium, Camarotæchia cf. serrata (M'Coy), Bellerophon, and Encrinurus punctatus.

This fauna, as a whole, is very different from that of the

Lower Llandovery.

Northern Area.—The Middle Llandovery can be identified also in the Northern Area, where it has much the same lithology as near Llandoverv itself. It has been examined mainly along the River Crychan east of Cefn House, and on the road leading from the Crychan valley to Cefn-y-gareg—the prominent ridge which overlooks the valley on the east, also in the Glynmoch Gorge. At the first-named locality the graptolite-bearing shales mentioned on p. 360 are succeeded by rubbly greenish-blue mudstones, which present the appearance of having suffered considerably from shear-This appearance is due, however, not so much to the intensity of the pressure that the rock has endured as to the composition of the rock, and may be observed in certain homogeneous mudstones of many different ages. These rocks yield Stricklandinia lens in abundance, together with a few other fossils, including in one locality Climacograptus hughesi. There is no evidence of unconformity; on the contrary, there is no obvious reason in the relations of the strata for separating these Stricklandinia mudstones from the underlying Llandovery rocks. The colour and other characters of the mudstones are not like those of any of the known Lower Llandovery deposits; but, in the absence of other evidence, this would scarcely be regarded as sufficient justification for assigning the strata to a new division of the formation. I entertain a strong suspicion, however, that in a short distance west of the stream-section the mudstones begin to overstep the Lower Llandovery.

On the east side of the ford over the Crychan, about 1000 yards upstream from this locality, there is a small excavation in very fossiliferous, dark-grey, sandy mudstones, containing Meristina crassa, Barrandella undata, Plectambonites duplicatus, P. mullochensis, P. scissus, Atrypa marginalis, Meristina subundata, etc., which clearly indicate that the horizon is within the uppermost group (A4) of the Lower Llandovery. The form of Barrandella undata which occurs here is unlike those from other Llandovery localities, and I am unable to say whether this horizon is higher than any observed elsewhere, or whether it may represent a lower horizon that does not happen to be exposed. I have not succeeded in identifying in this section the graptolitiferous band previously described, but it is possibly concealed under the streambed. If such be the case, then the above-mentioned fauna represents a higher horizon than is exposed lower down the Crychan, and its existence here would confirm the suspicion that the base of

the mudstones oversteps the Lower Llandovery towards the southwest. The examination of the remainder of the Northern Area will probably throw more light on these problems. These rocks are succeeded immediately by greenish mudstones containing

abundant Stricklandinia, but scarcely any other fossil.

At the sharp bend near the summit of the road leading eastwards out of the Crychan, certain shaly mudstones, lying some 500 to 600 feet above the base of the Middle Llandovery, yielded a considerable fauna of brachiopods and graptolites; many of the brachiopods appear to be new species. The following have been identified: -Barrandella ef. undata (c), Atrypa marginalis (c), Meristina subundata, Plectambonites sp. nov., Orthis calligramma var., Lingula sp., Climacograptus scalaris (c), Orthograptus cyperoides, Monograptus decipiens, M. cf. regularis, M. regularis, or M. jaculum, and M. cf. lobiferus. The shelly fauna recalls that of the upper group of the Middle Llandovery near the River Ydw. The association of Orthograptus cyperoides and Monograptus decipiens, together with forms of the M. reqularis and M. lobiferus types, proves that the beds lie within the zone of M. convolutus; but these occurrences are not sufficient to show whether the horizon is that of the lower part of the zone or the upper part—namely, the subzone of Cephalograptus cometa. A specimen of Monograptus decipiens was collected also near the top of the Middle Llandovery, in the Glyn-moch Gorge.

Since these graptolites occur at a considerable distance up in the stage, it is possible that the base of the Middle Llandovery lies as low as the zone of *M. cyphus*, and that the stratigraphical succession in this district is complete. General considerations and the existence of a proved unconformity at the base in the Southern Area render this unlikely. The lithology of the mudstones strongly recalls that of the *M.-leptotheca* and *M.-convolutus* Zones in Central Wales, and I believe that the true base of the Middle Llandovery probably coincides with the horizon at which a striking lithological change takes place in the Valentian rocks—namely, between the zone of *M. leptotheca* and that of *M. triangulatus*. It is significant, too, that at Rhayader the *M.-leptotheca* Zone was described by Dr. H. Lapworth under the name of Calcareous-Nodule Beds. That author remarks that the change

between these and the underlying beds

'is remarkable for its suddenness. So great is it that a knife-blade can be inserted into the plane at which one group ends and the other begins' (op. cit. p. 80).

Some evidence as to the probable upper limit of the Middle Llandovery will appear when we deal with the relations to it of the Upper Llandovery.

¹ 'The Silurian Sequence of Rhayader' Q. J. G. S. vol. Ivi (1900) pp. 67-137.

The Upper Llandovery Stage (C).

These rocks crop out along the ridge which runs from near Penlan, south-east of Llandovery, to the River Sefin. They are well exposed in several road-sections and in quarries. Fossils are abundant in some exposures, in others they are difficult to find. Whereas the underlying strata are affected by some folding, these rocks have a remarkably steady eastward dip and a nearly constant strike. Because of this uniform dip and the occurrence at intervals of shalv beds among the harder mudstones, the more resistant strata give rise to long, almost uninterrupted, rocky ridges, separated by depressions which coincide with the outcrop of the softer strata. By making use of such features it has been possible to subdivide the Upper Llandovery into several distinct groups, and to map these with comparative ease. The best and most continuous sections are found along three roads which cross the Penlan ridge and its southward prolongation—namely (in order from north to south), the Penlan road, the Cefn-cerig road, and the road leading from Blaen-y-cwm to Gorllwyn-fach near the southern end of the district.

(C1) Calcareous-Nodule Group.—This group is exposed in nearly continuous section in the lower part of the Penlan road. The lowest beds are, however, seen, not in the road, but in a quarry on the slope opposite Troedyrhiw Cottage, at the foot of the hill; they consist of pale, greenish, compact mudstones in thick beds, separated by rows of small, tough, calcareous nodules. A small quarry beside the road, about 150 yards above the cottage, is in similar mudstones, and Pentamerus oblongus, Barrandella cf. undata, and Meristina cf. subundata were found in it. The beds in this quarry dip north-westwards at 70° to 90°, whereas those in the first quarry dip south-eastwards, as do also the rocks in the remainder of the section. There is probably a sharp plication near the base of the section, so that the thickness of the group is less than the width of the outcrop makes it appear. In the southern flank of the fold the beds dip at first at 45°, but they rapidly become steeper, and in the upper third of the section they are vertical. In estimating the thickness of the group at 400 feet, allowance has been made for the effect of folding.

On the Cefn-cerig road, about half a mile away to the south-west, the section is very similar; the total thickness continuously exposed is 360 feet; but the lowest beds, which occur along the foot of the slope, are concealed. Few fossils have been obtained: these include Meristina cf. subundata, Barrandella cf. undata, Favosites fibrosus, a small species of Dalmanella, and Plect-

ambonites sp. nov.

The approximate position of the base is indicated by a prominent strike-feature; following this feature southwards, we arrive at exposures in a lower part of the group than is seen in the above-described sections. One of these is about 200 yards north of the

Round Lodge on the drive to Llwynywormwood, where a quarry has been opened in pale-greenish massive mudstones containing small calcareous nodules. Barrandella ef. undata is abundant in one thin seam, and is associated with Pentamerus oblongus, Leptæna rhomboidalis, Atrypa reticularis, Meristina ef. subundata, Triplecia insularis, Favosites fibrosus, and some others not yet identified.

Near the South Lodge entrance to Llwynywormwood the firstnamed two species can be collected in most exposures along the drive; but a brownish sandstone seen near the bridge east of the Lodge contained numerous specimens of a very small species of Holopella, which has not been seen elsewhere in the district.

But for the feature at their base, which marks off sharply these mudstones from the underlying strata, it would be difficult to distinguish them either by their lithology or by their fauna from the upper group (B₃) of the Middle Llandovery. In view of the relations between these groups in other parts of the district, this is somewhat surprising. The frequent occurrence of *Pentamerus oblongus* in the higher beds, although it is less abundant than *Barrandella*, serves usually to distinguish the two groups; but, inasmuch as this species makes its appearance at the base of the Middle Llandovery, this criterion cannot be used with absolute confidence. That the horizon adopted as the base of the Upper Llandovery is the correct one, is, however, demonstrated on the high ground south of the road from Pont-Pwll-defaid to Myddfai.

In this area the beds just above the feature which defines the base-line of the group are exposed in a continuous ridge for a distance of over 400 yards, and have a remarkably steady dip and strike. The strike was very carefully determined with the aid of a prismatic compass, at several points where a single bedding-plane was visible for a distance of several yards, and each observation may be assumed to be correct within 1° or 2°. It varies between east 15° south and east 21° south, the average of five observations being east 18° south. A few yards west of this ridge is a quarry in greenish-blue mudstones with well-defined bedding-planes. According to the mapping, the mudstones appear to lie near the junction between the upper and the middle groups of the Middle Llandovery, and, as they seemed to strike towards the ridge of Upper Llandovery rocks, a careful determination of their strike was made in the quarry. This gave a value of east 5° south, which proves a discordance in strike of from 10° to 16° between the two groups. Moreover, the upper group (B3) of the Middle Llandovery is largely missing. There is also a considerable difference between the dips of the two formations, the upper dipping at 48° and the lower at 28°. As there is an interval between the quarry and the ridge where the rocks are not exposed, the discordance might be explained by assuming either an unconformity or a strike-fault in this covered space. Fortunately, any uncertainty on this score is laid at rest when we examine the relations of the base of the Upper Llandovery farther south.

On the slope west of Gorllwyn-fawr Farm the lowest group (C_1) of the Upper Llandovery is more sandy than on the north, and of somewhat diminished thickness; with this change in lithology Pentamerus oblongus becomes relatively more abundant. beds on which the Upper Llandovery rests are of similar lithology, and contain a fauna similar to that of the Mudstone and Sandstone Group (A₃) of the Lower Llandovery; and about 300 yards farther south the base of that group is in contact with the base of the Upper Llandovery. There the two higher groups (A₂ & A₄) of the Lower Llandovery and the whole of the Middle Llandovery (B), representing a total thickness of about 1900 feet of strata, are missing. There is also a discordance in strike of about 20° between the two groups near their junction. At the base of the Upper Llandovery there is a small thickness of mudstones with large rounded grains of quartz, and presenting the appearance of basement-beds. Due north of Gorllwyn-fawr, and on the road from Cilgwyn to Gorllwyn-fach, these pebbly mudstones are separated from the Lower Llandovery by a small thickness of mudstones belonging to the lowest group (B1) of the Middle Llandovery. The occurrence of these pebbly mudstones at its base proves that the relation of the Upper Llandovery to the underlying beds is due to unconformity, and not to strike-faulting.

The next sections of interest are those on the River Sefin, south of Lletty'rhyddod. In the southern bank of the river, near the footbridge, massive sandstones containing frequent *Pentamerus oblongus* occur within 160 yards across the strike of the base of the Lower Llandovery. They dip north-westwards at 70° under the alternating series of mudstones and sandstones (A_2) previously described (p. 356); but this is due to inversion, and, as the outcrop is followed north-eastwards, the dip gradually rights itself. In this section all but about 450 feet of the Llandovery rocks have been overstepped (see sect. 3 in fig. 2, p. 362).

Close to the southern end of the footbridge, the Upper Llandovery sandstones contain an abundant and varied fauna, comprising the following forms:—Stricklandinia cf. lens (probably a different species), Atrypa reticularis var. orbicularis, Plectambonites scissus, P. undulatus var., Leptæna rhomboidalis, Orthis cf. reversa, Triplecia insularis, Strophomena antiquata, Favosites gothlandicus, Heliolites cf. parasiticus. Encrinurus punctatus, Illænus spp., together with other trilobites, brachiopods, lamellibranchs, gastropods, cephalopods, and erinoids not vet determined.

Underlying these beds, but stratigraphically above them, is a small thickness of dark-grey shaly mudstones, which are exposed in a cart-road leading down to a ford, a few yards above the footbridge. These dip north-westwards at 55°, and are strongly overturned. They are extraordinarily fossiliferous, but the fossils are many of them new or undescribed species, while others recall so vividly the fauna of certain Wenlock strata that the shales were at one time believed to be the basal beds of the undoubted Wenlock rocks,

which crop out only a few yards away to the east. Among the forms from this locality the commonest are: -Brachyprion fletcheri and Plectambonites segmentum, both of which are characteristic of the Wenlock formation. They are associated with Hebertella cf. lata and a new species of Leptostrophia. The true horizon of this fauna was discovered later, when a narrow ledge of rock exposed at low water at a sharp bend of the Ydw, 600 yards above the footbridge, was examined. A part of this ledge vielded the fossils typical of these shales, but in intimate association with them occurred abundance of Monograptus sedqwicki, with a few examples of M. tenuis. graptolite fauna proved a complete, but none the less welcome, surprise. The shelly fossils include various species of Plectambonites, especially P. segmentum and forms of P. undulatus, Schuchertella pecten, Leptæna rhomboidalis, Hebertella cf. lata, Leptostrophia sp., Atrypa barrandi, Phacops weaveri (?), Ph. elegans, Calymene sp., Homalonotus, etc.

The strata are inverted 10° to 15°; the shelly fossils lie mainly between the graptolite-band and the base of the group, and are, therefore, slightly the older. The intimate association of the fossils proves, however, that the shelly fauna truly belongs to the graptolite horizon (namely, the zone of Monograptus sedgwicki). and, from the relative abundance of that species in comparison with M. tenuis, it may be assigned to the upper part of the zone. The thickness of beds between this band and the base of the group is 150 feet: this probably corresponds in time to a small thickness only of graptolite-shales, so that the base of the Upper Llandovery at this locality may be assumed to be very nearly the base of the M.-sedqwicki Zone. The stratigraphical break and unconformity must, therefore, occur below that zone and above some part of the M.-convolutus Zone. It is of considerable interest to find that the marked unconformity discovered by Dr. Herbert Lapworth at the base of the Caban Group in the Rhayader district falls within the same limits of time.1

On the southern bank of the river, near the footbridge, there is a quarry about 40 yards away from the highest beds of this group, in dark-blue finely-striped shales, with an inverted north-westward dip at 40°, and clearly belonging to the Wenlock formation.

(C₂ & C₃). Lower and Upper Greenish Mudstones.— These are of little interest, and few fossils have been found in them; they are well exposed in the Penlan road, the Cefn-Cerig road, and in the road from Blaen-y-cwm to Gorllwyn-fach. On Penlan Hill, Platystrophia biforata, Barrandella cf. undata, and Dalmanella sp. were obtained from the lower group; as also Barrandella cf. undata, Plectambonites scissus, P. sp. nov., Stricklandinia sp., and Meristina cf. subundata from the upper group. The rocks were formerly quarried in Allt Rhyddings, and

¹ 'The Silurian Sequence of Rhayader' Q. J. G. S. vol. lvi (1900) p. 67.

about half a mile away to the north-east is another old quarry in a similar rock, in Allt Troed-rhiw-felen. This appears to be the Rhiwfelig quarry mentioned by former investigators. Just above the Allt Rhyddings quarry is a large spoil-heap of rock from the Old Penlan Lead-level, on which many fossils could formerly be picked up. On the road south of the quarry the beds are traversed by a sharp plication with a strong north-easterly pitch.

(C₄). The Sandstone Group.—This is the most distinctive, as well as the most fossiliferous, group in the Upper Llandovery. It consists of dark-grey or greenish, somewhat mottled muddy sandstone, traversed by an interlacing network of dark markings often dichotomously branched, which appear to be remains of fucoids. Bands of paler, hard, quartiztic sandstone also occur, and towards the middle of the group a fairly constant band of greenish sandy shales is noted.

Fossils can be found in almost every exposure, and are particularly abundant in a few localities, where layers or nodules of

sandy limestone have become decalcified to rottenstone.

This group is completely exposed, with a south-eastward dip of 65° to 70° near the summit of Penlan Hill, above and below the road to Penlan-Telych Farm. It was traversed also by the Penlan Lead-level, and the fossils on the spoil-heap above Allt Rhyddings quarry are mainly, if not wholly, derived from this group. One of the figured specimens of Atrypa (Barrandella) globosa was obtained there by Murchison, and I collected similar specimens from the same place. Near the base of the group on the Penlan road Pentamerus oblongus, Barrandella globosa, Plectambonites sp. nov., P. segmentum, and Monograptus cf. marri were obtained. These appear to be nearly the same beds as those formerly worked in the Penlan quarry in the field on the north. At the top the massive sandstones pass up gradually into pale-grey mudstones,

which belong to the overlying group.

A similar succession occurs on the ridge north of Penlan Farm. where the sandstones dip south-eastwards at 60° to 65°, and are succeeded in the farmyard and farther east by pale greenish-grey mudstones. Between this ridge and the Penlan road lies another ridge, on the north-western flank of which is the Penlan quarry. Here the sandstones, with abundant Pentamerus oblongus, dip north-westwards at 55°; but dipping under them are palegrey mudstones (exposed in the road to the farm) similar to those which, elsewhere in the district, overlie the sandstones. beds in this ridge are, therefore, greatly inverted. The inverted belt extends for about 250 yards along the ridge, and appears to be bounded on each side by north-and-south faults. One of these can be located closely in a small pit on the ridge due west of Penlan-Telych, where the sandstones dip south-eastwards at 65°, but a few yards south they are slightly inverted. The amount of inversion increases towards the Penlan quarry, though a short distance south-west of the quarry the beds have again righted

themselves. Although the faults are nowhere exposed, it appears impossible, in their absence, to account for so sudden a change in the attitude of the rocks.

Between the Penlan road and the Cefn-cerig road the Sandstone Group forms a well-defined ridge or, more usually, two parallel ridges, with an intervening shallow depression. About 500 yards north-east of Cefn-cerig Farm there is a quarry near the base of the upper sandstones. The main part of this quarry consists of massive, dark-grey, 'fucoidal' sandstone, dipping southeastwards at 72° and comparatively unfossiliferous; but along the western face the lowest layer exposed is a yellow sandy rottenstone containing a great variety of fossils. These include Atrypa reticularis, Barrandella globosa, Pentamerus oblongus, Stricklandinia sp. nov., Orthis calligramma var., Plectambonites segmentum, P. sp. nov., Leptana rhomboidalis, Brachyprion fletcheri, Strophomena cf. antiquata, Cyrtia exporrecta, Encrinurus punctatus, Illænus spp., Cheirurus sp., Phacops elegans, In the Cefn-cerig road, Barrandella globosa and Pentamerus oblongus occur commonly in the lower sandstones; a quarry lower down the road, and immediately above the farm, is at approximately the same horizon as that just described, and yielded many of the same fossils. Nearly opposite the stile leading to Cefncerig Farmhouse, the sandstones give place to the overlying pale mudstones.

From this locality the beds pursue a remarkably steady course with south-easterly dip to the neighbourhood of Llwyn Meredith Farm, south of the Myddfai road. On the slope west of the farm they are affected by folding, and their outcrop is much wider than elsewhere. A large quarry near Llwyn Meredith is in sandstone similar to that of the Cefn-cerig quarry, and yielded many of the same fossils, including the new species of Stricklandinia.

There is an almost continuous section through the group in the road above Gorllwyn-fach, between the quarry near the farm and the top of the wood. The sandstone-beds are very fossiliferous, usually yielding Pentamerus oblongus, Barrandella globosa, and occasional Spirifer radiatus. The rocks in the quarry do not now yield many fossils, but certain exposures on the same strike in the road above the quarry are very fossiliferous. The most abundant form is Barrandella globosa, which is associated with Atrypa reticularis, Brachyprion fletcheri, Plectambonites segmentum, P. sp. nov., Pentamerus oblongus, etc. This is the southernmost exposure of the group. It is distinguished from all the other Upper Llandovery rocks by the abundance of the large form of Barrandella globosa, in association with Pentamerus oblongus, Plectambonites segmentum, and a variety of trilobite species. So far as I have been able to determine, B. globosa does not occur at lower levels.

(C₅). The Pale Mudstone Group.—The gradual passage upwards of the sandstones into pale greenish-grey mudstones can

be examined in both the Penlan and the Cefn-cerig road-sections, and also at the lower end of the Gorllwyn-fach quarry. In the Cefn-cerig road, between the stile and the gateway leading to the farmyard, but on the opposite side of the road, a thin fossiliferous band in the lower part of the mudstones yielded abundance of fossils, including:—Barrandella globosa (small variety), Spirifer radiatus, Atrypa reticularis, Meristina cf. furcata, M. spp., Schuchertella pecten, Leptæna rhomboidalis, Plectambonites sp. nov. (like a form in the Onny River section). All these are very common; Pentamerus oblongus, Brachyprion fletcheri, Scenidium spp., Discina sp., Beyrichia klödeni, etc., occur less abundantly.

The higher beds of the group are exposed only near the stream, a quarter of a mile north of Llwyn Meredith. In the bank of the stream, where it forms a wide loop convex to the south, they yielded a fauna very similar to that enumerated above, together with Plectambonites segmentum, Lichas sp., Dalmanites

weaveri (?), Calymene sp., etc.

The most distinctive feature of this group is the abundance of *Spirifer radiatus* and of the small variety of *Barrandella globosa*. The group comes to an end a short distance south of Gorllwynfach. In the Northern Area, the well-known fossil locality, Castell Craig Gwyddon, traverses a part of the two groups just described (C_4 & C_5).

(C₆). The Green Micaceous Group.—East of Penlan greenish highly micaceous shales, which include numerous very thin bands of laminated micaceous sandstone, crop out east of the grey mudstones. The exposed thickness does not exceed 100 feet, and no fossils have been found in the group. It is not visible farther south, and there is reason to believe that it does not occur in that direction. Northwards, however, rocks of similar character occupy a large area on the eastern slope of the prominent ridge of Mwmffre, north of the Llandovery-Brecon road. Their disappearance southwards is probably to be attributed to overstep at the base of the Wenlock.

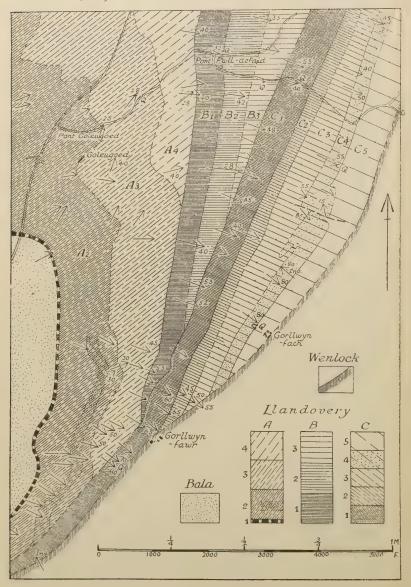
Wenlock Series.

Although it does not lie within the scope of this communication to give a systematic account of these rocks, it is necessary to refer to some exposures, especially those which are close to the boundary

with the Llandovery.

In the Gwern-felen road, north-east of Penlan, dark-grey, brown-weathering, finely laminated, flaggy shales crop out with a nearly vertical dip. They are so distinct in lithology from any of the Llandovery groups that they must be assigned to another formation. The same horizon, or a slightly higher one, is exposed on the Penlan road, and just inside the field graptolites were obtained from a thin seam in a small quarry. They are not well preserved;

Fig. 3.—Map of the southern portion of the Llandovery district, illustrating the mutual relations of the Lower, Middle, and Upper Llandovery rocks. (Scale: 3 inches = 1 mile, or 1:21,120.)



but all the specimens appear to be referable to Monograptus dubius, which is a characteristic Wenlock species. In a lane alongside the dingle, south of the last-named locality, there is a complete section for a distance of about 300 yards. The lowest beds are blue compact mudstones, which are separated by a gap of a few feet from the next exposure to the east, of finely striped brown-weathering shales similar to those described above. The blue mudstones may, in fact, belong to the Upper Llandovery Group (C₅); but no fossils were obtained in them. A few yards away the striped shales yielded Plectambonites segmentum and other indeterminate remains. The overlying beds contain minute fragments of a highly-sculptured shell, apparently a species of Bellerophon, and crinoid-ossicles. Near the foot of the hill Monograptus flemingi and Acidaspis sp. were associated with them.

Continuing along this lane, the striped shales are followed by greenish rubbly shales and some flaggy mudstones, which are exposed at intervals for a mile and a quarter east of the Llandovery boundary, and, as the dip in all exposures is 75° to 80°, it is evident that a considerable thickness is represented, although there may be some repetition by concealed folding. The only fossil found was a beautifully preserved specimen of Plectambonites segmentum.

Where the lane descends the eastern slope of Twyn-y-Fan, a mile and three-quarters south-east of Penlan, it traverses a group of different lithology: namely, grey shales with thin bands of rubbly fucoidal sandstone, and thicker beds of tough quartzitic sandstone showing a well-developed prismatic jointing. Some fossiliferous layers contained Plectambonites segmentum, Spirifer radiatus, Barrandella ef. linguifer, Wilsonia sp., Encrinurus punctatus, Atrypa marginalis, etc. These are the highest beds examined.

North of Llwyn Meredith dark-blue, brown-weathering, striped mudstones are exposed a short distance downstream from the localities which yielded Llandovery fossils. At Gorllwyn-fawr (see fig. 3) the lowest group (C_1) of the Upper Llandovery is exposed at the well by the roadside; but in the ditch, a few yards away, there is an exposure of a dark-blue striped mudstone unlike any Llandovery rock, yet closely comparable with that in the stream near Llwyn Meredith. There is little doubt that it is of Wenlock age, and that formation is, therefore, separated by a space of a few feet only from a low part of the Upper Llandovery; whereas near Gorllwyn-fach, half a mile away to the east, all the Upper Llandovery groups are present. Between Gorllwyn-fawr and Gorllwyn-fach a small stream crosses the road which follows the foot of the hill, and below the road it has excavated a short ravine. Above the road, and for about 80 yards below, the stream traverses the two Upper Llandovery groups of greenish mudstoner (C₂ & C₃). The upper group (C₃) is followed abruptly by striped dark-blue mudstones with thin fossiliferous seams, which yielded

Plectambonites segmentum, Spirifer radiatus, Meristina tumida, Orthoceras annulatum, and minute fragments of Bellerophon (!). There is no doubt that these striped shales should be referred to the Wenlock, which is, therefore, in contact with much higher beds of the Llandovery Series than at Gorllwyn-fawr. Although the junction has not been precisely located, there is no evidence of faulting in the ravine, and it is probable that the relation of the Wenlock formation to the Llandovery is one of unconformity with rapid overstep. There is, in fact, a marked discordance in dip and strike between the two formations near their junction: the Llandovery mudstones dip east 22° south at 50° and the Wenlock east 50° south at 73°, diminishing downstream to 55°. The latter strike agrees with the trend of the boundary between the formations from the ravine to Gorllwyn-fawr, where again it can be located within a few feet.

An unconformity at the base of the Wenlock Series would also explain the disappearance, one after the other, from north to south, of the Upper Llandovery groups (C_6 to C_2), leaving only the lowest group (C_1) to persist towards the Sefin (see fig. 3, p. 374). Further, there is no evidence along the base of the Wenlock of the zone of Cyrtograptus murchisoni, and the occurrence near the base of Monograptus dubius (which is usually found at a higher level than that zone) suggests that the unconformity is attended by overlap within the formation. This is in accordance with the behaviour of the Wenlock Shales farther north, in the neighbour-

hood of Builth.1

Some further support to this suggestion is given by the fact that, near the Sefin valley, shales with bands of quartzitic sandstone showing marked prismatic jointing occur within a distance, across the strike, of less than 900 yards from the base of the formation; whereas east of Penlan such beds were only reached at a distance of a mile and three-quarters. Also, by the fact that the lowest beds of the Wenlock Series exhibit a different type of lithology in almost every section.

IV. SUMMARY OF THE GEOLOGICAL HISTORY OF THE DISTRICT.

In the Llandovery district we can distinguish between the top of the Upper Bala and the base of the Wenlock Series three stages of the Llandovery Series, each comprising several rock-groups, which appear to have been laid down continuously under nearly uniform conditions. There is, however, conclusive evidence that the stages are separated by marked unconformities, demonstrating that the rocks have been subjected to more than one period of uplift and subsequent erosion. Within each stage we can recognize certain phases of deposition, distinguished one from the other by

¹ G. L. Elles, 'The Zonal Classification of the Wenlock Shales of the Welsh Borderland' Q. J. G. S. vol. lvi (1900) p. 371 & p. 385, fig. 4.

the relative abundance of the muds and the sands that were

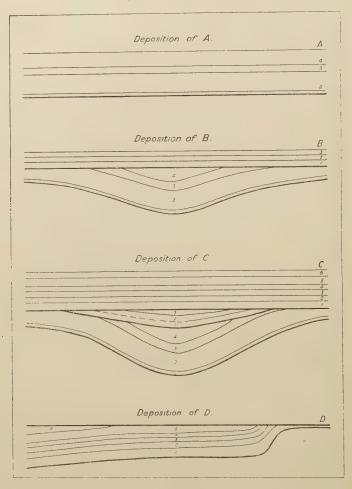
brought into the area.

The Upper Bala period was, on the whole, a muddy phase; but, towards the close, there was an interruption of these conditions, which lasted into the lower part of the Llandovery. This restricted phase is indicated by the occurrence among the prevailing mudstones of numerous thin beds of grey sandstone and an occasional wedge of imperfectly sorted conglomerate. At the beginning of the Llandovery (A1) there was a rapid return to a muddy phase; but the muds that were deposited differed from those of the preceding period in being finely laminated and in containing a larger amount of iron, which now appears on weathering as rusty stains on the rock-surfaces. This phase was followed by another (A₂), during which uniform greenish muds were laid down in thick beds in a part of the district. Towards the south these were replaced more or less completely by sandy beds, while towards the north they became more finely grained, darker, and pyritous. There is little, if any, evidence that organisms lived during this phase on that part of the sea-floor where muds were accumulating; but, with the incoming of sands farther south, the occurrence of certain fossils indicates the near approach to an area where shellbearing organisms lived, and from which their remains were swept into the area of deposition along with the sands and rather abundant mica. Towards the close of the mudstone phase the amount of sand brought into the area gradually increased; this is shown by the more sandy character of the mudstones, and by the presence of thin bands of sandstone among the argillaceous sediments. During the earlier part of the succeeding sandy phase was formed a group (A3) in which there is a fairly regular alternation of mudstones and thin bands of relatively coarse sandstone. Many of the latter are calcareous, and often contain scattered fossil shells and shell-fragments. There is abundant evidence that, during the deposition of the sandstone-bands, the materials were borne by fairly strong currents, capable, occasionally, of carrying pebbles up to a quarter or half an inch in diameter. Numerous flakes of white mica are also noticeable in these beds, while the frequent presence of one valve only of certain brachiopods suggests that the shells were transported or drifted into the area during those periods when strong currents prevailed. The absence of fossils in the intervening mudstones appears to prove that the shelly organisms did not live in the area where their remains are now found, but in regard to the majority of the shells it is not probable that they had been drifted for any considerable distance, possibly not more than a few hundred yards.

At a higher level, muds containing a large proportion of sundy material and occasional pebbles of the size of a pea were laid down, and in the resulting sandy or pebbly mudstones we find, from the frequent occurrence of shells throughout the rock, some evidence that we are dealing with the remains of the indigenous life of the

period.

Fig. 4.—Diagram illustrating the geological history of the Llandovery district (Southern Area).



[Note.—This diagram represents the relations of the strata in the direction of the general strike, the centre of the diagram being near Cefn Rhuddan. The total length is about $5\frac{1}{2}$ miles, and the vertical scale is twice the horizontal scale.]

These changes in lithology were probably the effects of spasmodic uplifts of the land-area bordering the basin of deposition, which were possibly attended by movements of the sea-floor. Such movements would result in the distance of the area of deposition from the coast-line being increased or diminished. The relative relief of the land-mass would also have an effect upon the nature and amount of the materials carried into the sea.

During the transition from the Bala to the Llandovery Stage the shore-line lay east of the area, and probably not far away. The majority of the shelly fossils lived on the sea-floor, very likely in shallow water, near the shore-line, and their remains were occasionally drifted by tides and currents; this happened the more frequently as the tract of shallow water in which they could live approached nearer to the area where these remains are now found. The situation of these shallow-water tracts may have been determined or changed from time to time by uplift of the land-area or by the piling-up of deposits on the sea-floor. During the latter part of the Lower Llandovery period such tracts apparently lay within the district where these rocks now crop out.

That period was brought to a close by uplift which caused the removal of some of its deposits. The maximum uplift and consequent erosion occurred in the north and in the south of the district, and the minimum uplift in the centre, where the succession is most fully represented. The Lower Llandovery rocks were accordingly folded into a basin, and the axes of uplift appear to have lain transversely to the present strike of the rocks, although

their trend cannot be precisely determined.

After an interval, the length of which can be estimated only within fairly wide limits, when the rocks were exposed to denudation, deposition was resumed during Middle Llandovery time. The rocks of this period were laid down on the eroded edges of the Lower Llandovery strata (see fig. 4), but the shore-line on the east appears to have lain at about the same distance away as it did immediately before the uplift. Many of the fossils occur in the mudstones, and there is less evidence of drifting than in the early

part of the Lower Llandovery period.

The Middle Llandovery was, in turn, brought to a close by renewed movement, in the course of which the strata were folded into a shallow basin which coincided almost exactly with that already existing in the underlying Lower Llandovery, which was, in consequence, made deeper than before (see fig. 4). So far as can be determined, the position of the axes of renewed elevation coincided with those of the preceding uplift. After another interval of erosion, the Upper Llandovery deposits were laid down upon the planed-off edges of the Middle Llandovery rocks, and overstepped both north and south on to the Lower Llandovery deposits.

The physical conditions during the deposition of the lower groups of the Upper Llandovery appear to have been similar to those which prevailed in the Middle Llandovery. Despite the magnitude of the Upper Llandovery unconformity indications of

basement-beds are found only in one part of the outcrop (near Gorllwyn-fawr). It is possible that the sediments were not elevated above sea-level, but were removed by current-action while they were still only in part consolidated. This would account for the absence of more striking indications of wave-action at the base of the unconformable strata.

The fucoidal sandstones (C₄) were formed when shallow-water conditions favourable to a varied and abundant organic life appear to have occurred over a large area, since their fauna has a wide distribution in Upper Llandovery rocks outside the type-area.

The succeeding groups (C₅ & C₆) indicate, by the prevailing pale-green colour of the mudstones and the barrenness in fossils of most of the beds, that, towards the close of Upper Llandovery time, conditions again became unfavourable to life. Such conditions may well have foreshadowed the renewed uplift which occurred at the close of the period, and before the deposition of the Wenlock rocks. During the interval of erosion that followed this uplift all but some 200 feet of the lowest Upper Llandovery rocks were removed in places. Near the southern end of the district the Upper Llandovery rocks were sharply arched-up and in that altitude planed-off, thus allowing of their rapid overstep by the base of the Wenlock Series near Gorllwyn-fawr. North of that place higher groups of the Llandovery emerge from underneath the Wenlock beds, and this process appears to continue into the Northern Area.

During the phase of deposition that followed this erosion dark-grey graptolitiferous muds were laid down; they are readily distinguished from all Llandovery sediments by their fine banding. There is some evidence, too, that these Wenlock rocks were laid down on a surface of Llandovery deposits which sloped gently from south-west to north-east, and that in consequence the lowest zone (or zones) of the formation, has been overlapped before it reaches the district east of Llandovery. These basal beds are succeeded towards Mynydd Bwlch-y-Groes by a great thickness of higher Silurian rocks, which appear to have been deposited without

further interruption.

The existing structures of the rocks are due in the main to the Caledonian or post-Silurian earth-movements. Broadly considered, the district lies on the south-eastern flank of the Towy Anticline, and in general the beds dip steeply away from its axis (see fig. 2, p. 362). In places, as in Cefn Rhuddan Wood and on the north, and again near the River Sefin, the rocks are strongly overturned

(see pp. 357, 369, 382).

The Upper Llandovery rocks are almost free from folding, only four instances having been observed along the whole outcrop: namely: in the lower group (C_1) near Troedyrhiw Cottage; in one of the higher groups (C_3) near Allt Rhyddings quarry; in the Sandstone Group near Llwyn Meredith; and in the underlying mudstones (C_3) on the road from Blaen-y-cwm to Gorllwyn-fach. In each of these localities the rocks are affected by an exceedingly sharp plication with a north-easterly pitch. On the other hand,

the Lower Llandovery rocks are traversed by many folds. remarkable effect of this small-scale folding on the topography may be observed south-west of Cefn Rhuddan. If we stand on the high ground formed by the higher groups (A, & A₄) of the Lower Llandovery, the rocks may be seen to have a very steep dip and a remarkably steady strike towards the south-west; but, if we look in that direction, we see facing us the prominent Cilgwyn escarpment, trending almost at right angles to the direction of strike of the rocks on which we are standing. The Llandovery and Bala rocks of that escarpment do, in fact, strike nearly at right angles to those of the Cefn Rhuddan ridge, and one would almost infer from the relations of these two ridges that the rocks which formed them belonged to different formations, separated either by a great fault or a pronounced unconformity. The examination of the intervening ground and of the area south-east of the Cefn Rhuddan ridge provides an explanation of these relations.

The dip of the beds in the Cilgwyn escarpment swings gradually from east-north-east (at the western end) to north-east, and finally (at the eastern end) to due north. East of Cilgwyn it swings round again to east-north-east, and finally to south-east. This arrangement represents a shallow syncline west of Cilgwyn, and a complementary anticline in the Ydw valley near that place. The syncline is not, however, a simple one, but is traversed by some shallow undulations. In addition, the outcrop is displaced repeatedly by dip-faults varying in direction between north and north-east. These faults apparently die away, or more probably are replaced by folds in the overlying mudstones. At the same time, the shallow undulations in the syncline become accentuated in the overlying beds, which are affected by many folds, all of which pitch north-eastwards: that is, in the general direction of the axis of the shallow syncline. Such folding is well exhibited in the lower beds of the Mudstone and Sandstone Group (A3), and in consequence thereof the base of the group trends in a direction which makes a large angle with the strike as determined in most of the exposures. This is a well-known effect of pitch, and to it may be attributed the abrupt termination of the Cefn Rhuddan ridge south-westwards, and the fact that, beyond its termination, the outcrop of the beds that form it trends south-eastwards nearly at right angles to the direction of the ridge.

The small-scale folding is flattened out again in the higher beds, and almost disappears before the top of the Lower Llandovery is reached. It is thus most pronounced in the relatively soft mudstones of that stage, and tends to die away in the harder and more resistant overlying rocks. The steep dips and the inversion of the rocks along the western margin of the district imply that the push was directed mainly from the west towards the east. The eastern limb of the Cilgwyn anticline is also in places strongly overturned; whereas its western limb, as shown by the beds in the Cilgwyn escarpment, has, on the whole, a gentle dip. The yielding of the great mass of Lower Llandovery (and

probably Middle Llandovery) beds near Cefn Rhuddan has, to some extent, protected the Upper Llandovery rocks east of that district from severe folding. The almost complete absence of the Lower Llandovery rocks near the southern end of the district may, therefore, account for the severe overturning which the Upper Llandovery, and still more, the Wenlock rocks, have suffered near

the River Sefin (see fig. 2, sect. 3, p. 362).

At the western end of the Cilgwyn escarpment the Basement Beds of the Llandovery appear to be cut off by a fault near the Llangadock road. West of that road are outcrops of Bala mudstones only, and along the whole of the western margin of the Llandovery area similar mudstones, containing in places thin bands of laminated sandstone, are in contact with the Mudstone Group (A_2) of the Lower Llandovery. The characteristic Basement Beds are nowhere exposed, and it is probable that this margin is everywhere defined by a strike-fault which follows the eastern side of the Towy valley as far as Cwm Rhuddan, and thence crosses over the ridge west of Cefn-yr-Allt into the Gwydderig valley.

In this valley the Bala beds along the Brecon road, near the first milestone from Llandovery, dip north-westwards at high angles. In a quarry a few yards north of the road they are traversed by an isoclinal fold; the axial plane of the fold dips westwards. It is probable, therefore, that the north-westward dip in this section is due to isoclinal folding, and that the ascending succession is eastward, as in the district farther south. This belt of folding is thus the northern continuation on the line of strike of the tract west of Cefn Rhyddan. The faulted western margin of the Llandovery area probably lies a short distance east of these road-exposures.

In the Llandovery district we have recognized within the Llandovery Series three stages having unconformable relations one to the other, and the series is overlain unconformably by the Wenlock deposits. Each of these stages is characterized by a shelly fauna; but the discovery in some localities of graptolites has made it possible to determine the position of the shelly faunas with reference to the graptolite-zones of Wales, the Lake District, and the South of Scotland. While I refrain from entering into a detailed correlation with the graptolitic succession of the Valentian rocks, it may be stated that the three stages at Llandovery correspond broadly to the Lower Birkhill, Middle Birkhill, and Upper Birkhill, together with the Gala, respectively. A significant fact that emerges from the study of this district is that the physical base of the great mass of Gala rocks lies below the zone of Monograptus sedgwicki, and not immediately above that zone, as hitherto believed.

There is a gradual transition from the beds that yield M. sedgwicki, upwards into the shelly rocks which are the equivalents of the Gala graptolitiferous beds. This was also the conclusion at which Dr. Herbert Lapworth arrived in the Rhayader district.

Q. J. G. S. vol. lvi (1900) p. 107.

This discovery will render necessary some revision of the boundary between the Lower and the Upper Valentian, which must obviously be drawn at the base of the unconformable Upper Llandovery, or, in other words, at the base of the Upper Birkhill. The zone of M. sedgwicki will thus form the basal zone of the Upper Valentian, and not the uppermost zone of the Lower Valentian, to

which position it has been customary to assign it.

The shelly faunas of the Lower and of the Upper Llandovery Series have previously been recognized in many districts, but the shelly fauna of the strata corresponding to the Middle Llandovery was previously almost unknown. The pronounced unconformity and faunal change between the Middle and the Lower Llandovery should also be taken into account in delimiting the boundary between Lower and Middle Birkhill; it is known that the former is nearly the equivalent of the Lower Llandovery, and that the latter includes a large part of the Middle Llandovery Stage.

In conclusion, I wish especially to thank Mr. R. C. B. Jones, now of H.M. Geological Survey, for valuable assistance in collecting fossils from these retractory rocks. He it was who first discovered the graptolites of the M.-sedgwicki Zone on the River Ydwprobably the most significant fossil find made in the district. Mr. W. Thomas, then a student at Cambridge University, also accompanied me for a few days, and assisted in the fossil-collecting.

APPENDIX I.

Localities mentioned in the 'Silurian System.'

(a) Those from which fossils are recorded.

1. Blaenycwm, near Sardis (p. 642). Nautilus (Lituites?) undosus [N. undatus on p. 351] is recorded from 'dark sandy grits flanked by schist and dark-grey, white-veined, quartzitic sandstone.

This quarry, which is discussed on p. 351, lies 180 yards east of

Blaenycwm House.

2. Castell Craig Gwyddon (pp. 637, 638, 641). Atrypa (Barrandella) globosa, Spirifer radiatus var., Pentamerus oblongus, and P. lævis are

This is a great landslip scar, and possibly also a quarry, on the eastern flank of Noethgrug, 5 miles east-north-east of Llandovery. The scar traverses parts of the two higher groups of the Upper Llandovery (C4 & C5); the fossils were probably obtained from the

abundant loose blocks of rock at the foot of the scar.

3. Cefn Rhyddan (pp. 636-40). Atrypa (Meristina) crassa, A. (Barrandella) undata, A. (Stricklandinia) lens, Leptæna sericea var. [Plectambonites duplicatus], and Terebratula [? Camarotæchia] pusilla are recorded. On p. 661, a new species of Calymene differing from C. blumenbachi is noted.

This locality is probably the small quarry, now almost overgrown, in the wood 360 yards due north of Cefn Rhuddan farmhouse. The rock lies near, or at, the base of the highest division (A_{\downarrow}) of the Lower Llandovery.

4. Cefn y Garreg [Cefn-y-gareg], or west side of Cefn-y-Garreg (p. 637). This is mentioned on p. 353, and a new species of Lituites, Atrypa

(Barrandella) undata, A. rudis (not described or figured), Productus sericeus [Plectambonites duplicatus], Orthis actonia [?], and O. flabellula [?] are mentioned. On p. 643 Lituites cornu-arietis (β) is recorded from this locality, 'in black schistose beds of passage from the Silurian into the Cambrian,' and on p. 661 a Calymene like that from Cefn Rhuddan.

The locality can be identified accurately as the small exposure in the road-bank, about 40 yards east of the ford over the Crychan, a mile and a quarter east-south-east of Llanfair-ar-y-Bryn Church. The rocks are probably the highest beds of the uppermost group (A_4)

of the Lower Llandovery.

 Cerrig-gwynion (Cerig-gwynion). Leptena sericea is recorded on p. 636, and on p. 353 the same fossils are said to occur as at Cefn-y-gareg.

This name is apparently used for the ridge that lies west of the Crychan valley, and strikes parallel to Cefn-y-gareg. The rocks that yield fossils along this ridge consist of parts of the lower groups

 $(A_3 \text{ and } A_4)$ of the Lower Llandovery.

6. Goleugoed (pp. 636, 638-42, 693). On p. 351 Murchison states that the 'hill of Goleugoed has proved richer in fossils than any other portion of the tract.' Leptena sericea [probably Plectambonites duplicatus or P.-mullochensis], L. depressa [rhomboidalis], Orthis radians [?=0. calligramma var.], Orthis [Hebertella] protensa, O. [Hebertella] lata [cf. protensa], Spirifer [Orthis] plicatus, Terebratula tripartita [? Platystrophia biforata], Orthoceras annulatum, and Turbinolopsis [Petraia?] bina. Again, on p. 351, he refers to quarries at Goleugoed and some other localities in the district.

The only large quarry near Goleugoed is that known as Cwar-mawr, or Cwar-mawr Cilgwyn, which is on the roadside half a mile north-north-east of Goleugoed farmhouse. As this is the nearest house in sight from the quarry it would be natural to refer the locality to it. The quarry lies in the Mudstone and Sandstone Group (A₃) of the Lower Llandovery. Hebertella protensa was, however, more probably obtained from Middle Llandovery beds which occur some distance east

of the quarry.

7. Gorllwyn (pp. 352, 640). On the former page reference was made to a hill north of Castell Craig Gwyddon which lies west of Gorllwyn farmhouse. On the latter page Orthis lata [Hebertella cf. protensa] is recorded.

This fossil locality may refer either to Gorllwyn-fawr or to Gorllwyn-fach, south-west of Myddfai, in the southern part of the district. Good exposures of Upper Llandovery rocks occur near both places. The ridge of Gorllwyn in the northern part of the district consists partly,

if not wholly, of Upper Llandovery rocks.

8. Gorllwyn-fach (pp. 637, 642). Atrypa orbicularis [A. reticularis var.], A. [Barrandella] globosa, and Orthoceras bisiphonatum are recorded from this locality. Barrandella globosa occurs abundantly in association with A. reticularis in the upper part of the Sandstone Group (C₄) of the Upper Llandovery, in the road-bank just above the large quarry near the above-mentioned farmhouse. The fossils were probably obtained from the same beds in the quarry.

9. Mandinam (pp. 636-38, 640-42). The fossils recorded from here are:

Leptwna depressa [rhomboidalis], Atrypa [Stricklandinia] lens, Orthis
alternata [?], O. testudinaria [?], Terebratula [Camarotœchia?]
neglecta, Pleurotomaria angulata, Turbo (?) pryceæ, and Turritella

cancellata.

The basal group (C_1) of the Upper Llandovery occurs near the Sefin footbridge below Mandinam Wood. It is probable that the fossils were obtained from that locality.

10. Noeth grug (p. 638). Spirifer? lævis [?].

This is the name given to an upland tract, about $4\frac{1}{2}$ miles north-east of Llandovery. Rocks of Upper and Lower, and possibly of Middle, Llandovery age occur in its neighbourhood.

(b) Other localities.

 Cefn Llwydlo (p. 353). This tract lies west of the ridge of Ceriggwynion, and is probably composed of Upper Bala rocks.

2. Glasallt-fach, 'near the summer-house on the point of the hill,' and

'western end of the hill near the high road' (p. 353).

These localities lie on the Cilgwyn escarpment; at the former Murchison noted the thinly-bedded micaceous sandstones which I attribute to the Bala Series, and at the latter the coarse quartzose sandstones of the basal Llandovery group. All these beds are referred to the Caradoc Sandstone.

3. Cwm-clyd (p. 353). A small synclinal basin on the summit of the ridge

north-east of the farmhouse is described.

This locality is three-quarters of a mile due east of Glyn-moch (see next locality).

 Glyn-moch (p. 353). The beds of quartzose sandstone in the banks of the gorge near Glyn-moch are described.

The gorge is on a tributary of the Crychan, a mile and a half southsouth-east of Llanfair-ar-y-Bryn Church, and traverses the Upper and Middle Llandovery rocks.

5. Gorllwyn ridge (p. 352). This is the northern continuation of the Castell-Craig-Gwyddon ridge, and consists mainly or wholly of Upper

Llandovery strata.

6. Llwyn-y-wormwood (p. 351). Reference is made to a quarry (or quarries)

at this place.

Llwyn-y-wormwood House stands on the uppermost Llandovery rocks. There is a small quarry in the Sandstone Group (C_1) on the ridge about a quarter of a mile south of the house (see App. II); but the locality mentioned is probably that by the side of the northern drive 200 yards above the Round Lodge, where the basal beds of the Upper Llandovery have been quarried.

7. Mwmfre hills (p. 352).

This is a prominent hill north of the Brecon road, about $2\frac{1}{2}$ miles from Llandovery. The rocks are mainly Upper Llandovery.

8. Pant-dreinan (p. 353).

This appears to have been a name used for the very striking amphitheatre-like synclinal basin of Upper Llandovery rocks at the northern end of the Cefn-y-gareg ridge.

9. Rhiwfelig quarry (p. 351).

This is probably a quarry in Upper Llandovery rocks in Allt-Troedrhiwfelen (Troedrhiwfelin on the 1-inch Geological Survey map) about a mile and a quarter east-south-east of Llandovery.

APPENDIX II.

Fossil Localities represented by Fossils in the Museum of Practical Geology, London.

[Many of these localities have been discussed in Appendix I.]

Blaen-y-cwm (pp. 63-68) and Blaen-y-cwm Ridge (p. 70). See Appendix I.

A large and varied list of fossils is recorded from this locality. Those such as Pleurocystites rugeri, Phacops conicophthalmus, Calymene blumenbachi var. caractaci, Ptilodictya fuccides, Leptæna transversalis [=Plectambonites ruralis Reed], Orthis (Dinorthis) porcata, were probably obtained from the same spot, and form a typical Upper Bala assemblage. The record of Atrypa reticularis suggests that

¹ See 'Catalogue of the Cambrian & Silurian Fossils in the Museum of Practical Geology' 2nd ed. 1878.

fossils obtained from the ridge east of Blaen-y-cwm, between that place and the River Sefin, may have been recorded under this name as being the nearest place available for reference.

2. Castell Craig Gwyddon (pp. 69-75, 77, 78) or Craig-yr-wyddon (p. 73). See Appendix I.

3. Cefn Llwydlo. See Appendix I.

4. Cefn Rhyddan (pp. 28, 47, 64-66). See Appendix I. Fossils may have been collected from exposures in the wood west of the farmhouse, as well as in the quarry. On p. 28, Orthis striatula [Dalmanella testudinaria] from this locality is assigned to the Upper Llandeilo.

5. Cefn-y-garreg (p. 62) and west side of Cefn-y-garreg (pp. 62, 69). See

Appendix I.

6. Cilgwyn (pp. 49, 67) and north of Cilgwyn (p. 65). Under these names it is possible that fossils from more than one locality are included, but it is more likely that both refer to the quarry known as Cwar-mawr

Cilgwyn or Cwar Goleugoed. (See p. 358.)

 Coldbrook (p. 78). This locality probably refers to the Old Quarry in the basal Upper Llandovery rocks on the Cefn-cerig hill, 400 yards above Coldbrook Cottages, three-quarters of a mile south-east of Llandovery. These cottages would be the most natural place to which to

refer fossils collected in that quarry.

 Doaugwynon (p. 70). This is probably a misprint for Dolaugwynion, which stands 300 yards north of the Brecon road, 2½ miles from Llandovery. There is a small quarry in the Sandstone Group of the Upper Llandovery, on the cart-road a quarter of a mile east of the farm, and near the farm there are some exposures probably of the lower part of the Upper Llandovery. It is not likely that fossils from any other rocks were obtained in the neighbourhood.

9. Golengoed (pp. 63, 65, 67). See Appendix I. On p. 68 there is a reference to Golengoed, Pumpsant. There is a place of that name south of Pumpsant, near which there is an outcrop of grit from which

the fossil was probably obtained.

10. Gorllwyn-fach (pp. 64, 65, 67, 73). See Appendix I.

11. Gorllwyn-fawr, north of (p. 64). This may refer either to some locality in the Upper Llandovery rocks, which are well exposed in the neighbourhood, or more probably to exposures on the road from Blaen-y-cwm to Gorllwyn-fach, where the fossil recorded (namely, Stricklandinia lens) occurs commonly at a point due north of the farmhouse.

12. Llwyn Meredydd (pp. 71, 72, 74, 78) or Llwyn Meredydd quarry (p. 72). This clearly refers to the quarry in the Sandstone Group (C4) of the Upper Llandovery on the roadside to Llwyn Meredith, 450 yards

north-west of the farmhouse.

 Llwynywormwood (p. 73). See Appendix I (b).
 Mandinam (pp. 62-67, 69, 73, 75, 76, 78). See Appendix I.
 Mwmfre, west of (pp. 72, 75). See Appendix I (b). It is probable that the fossils were obtained from Upper Llandovery rocks.

16. Noeth Grug (p. 64). See Appendix I.

17. Penlan or Pen-y-lan (pp. 63, 64, 69-75, 77). Penlan-Telych Farm, usually designated 'Penlan,' stands on the ridge of Upper Llandovery rocks a mile and a half from Llandovery. Fossils have been collected in the past from several localities near this place: (a) a quarry in Upper Llandovery sandstone (C_{\downarrow}), in the field 230 yards south-west of the house; (b) the spoil-heap at the mouth of an old level driven from the wood 300 yards west-south-west of the quarry into the same sandstone group, in search of lead-ore; and possibly (c) from any of the abundant exposures on the road, or (d) from the quarry just below the tip from the lead-mine in Allt Rhyddings. Except in the Sandstone Group, which crops out near the top of the hill, the rocks in the road-exposures yield very few fossils, and the rocks in the quarry appear to be almost barren. The records probably refer, therefore, to fossils obtained from the field-quarry or from the tip, and in both cases they were derived from the Sandstone Group.

(C₁).

18. Trallwng Myddfai (p. 75). There is a farm named Trallwm on the 6-inch Ordnance Survey map, a quarter of a mile south of Llwynywormwood, and three-quarters of a mile north-west of Myddfai. The locality to which reference is made is probably the quarry in Upper Llandovery Sandstone (C_1), on the slope 280 yards west of the farm.

It will be seen from the following list that many of the localities are assigned to the wrong horizon. This is particularly the case with those referred to the Lower Llandovery. The localities which are probably erroneously assigned are in spaced type.

Caradoc. - Cefn Llwydlo, Cefn Rhyddan, Cilgwyn.

Lower Llandovery.—Blaen-y-cwm, Cefn Llwydlo, Cefn Rhyddan, Cefn-y-garreg, Cilgwyn, Goleugoed, Gorllwyn-fach, Gorllwyn-fawr, north

of (?), Mandinam, Noeth Grug (?), Penlan.

Upper Llandovery.—Blaen-y-cwm Ridge (f), Castell Craig Gwyddon, Cefn-y-garreg, west side of, Coldbrook, Dolaugwynion, Gorllwyn-fach, Llwyn Meredydd, Llwynywormwood, Mandinam, Mwmfre, west of, Penlan, Trallwng.

APPENDIX III.

Fossils in the Sedgwick Museum, Cambridge.

Most of the Llandovery localities are included in Salter's 'Catalogue of Cambrian & Silurian Fossils'. (The pages in this catalogue are inserted in parentheses.)

Lower Llandovery.

1. Blaen-y-cwm. (See Appendix I & Appendix II.)

2. Cefn-raltisa [? Cefn-yr-allt-isa]. This is probably the farmhouse situated on the mudstone group (A_2) of the Lower Llandovery, about 1 mile south of Llandovery. The overlying group (A_3) yields fossils on the slope south of the farm.

3. Cefn Rhyddan (pp. 79, 82). See Appendix I & Appendix II.

4. Cwar-mawr, Cilgwyn (p. 79). See Goleugoed and Cilgwyn. Appendix I

& Appendix II.

5. Goleugoed (pp. 73, 74, 77, 78, 80-82). See Appendix I & Appendix II. Atrypa reticularis and Orthis (Hebertella) protensa are recorded, among many others, from this locality. It is possible that some fossils may have been obtained from the small roadside quarry in Middle Llandovery rocks, 350 yards due east of Gloigoed [Goleugoed]-fach (now in ruins).

6. Mandinam or Mandinam Wood (pp. 79, 80, 83). See Appendix I &

Appendix II, and also No. 9 below.

- 7. Mwmfre, or ridge west of 'm' in Mwmfre. See Appendix I & Appendix II. The beds marked on the 1-inch Geological Survey map (Old Series, 41) as occurring in this position lie near the base of the Upper Llandovery.
- Llandovery.

 8. Pantygaseg. The farm of this name lies a quarter of a mile north-east of Pont Pwll-defaid on the road from Cilgwyn to Myddfai. The boundary between the upper group (B₃) and the middle group (B₂) of the Middle Llandovery passes through the farmyard. Fossils may be obtained near the farmhouse, but were more probably collected along the River Ydw south or east of the farm. Any fossils so recorded are likely to be from Middle Llandovery rocks.

 Sefin (or Sefin Llettyrhyddod) or Llettyrhyddod (pp. 79, 81, 82). On one of the tablets a fuller description of this locality by Prof. T. McKenny Hughes reads:— Footbridge, Sefin below Mandinam Wood, opposite Llettyrhyddod.' This description refers to the locality described on p. 369, and probably explains why the same place is mentioned under a variety of names, such as those noted above, also Mandinam and Mandinam Wood (see Appendix I & Appendix II).

Upper Llandovery.

1. Castell Craig Gwyddon (pp. 85, 87). See Appendix I & Appendix II.

2. Noeth Grug (pp. 79, 80). In the Catalogue this locality is referred to the Lower Llandovery, but the fossils are now placed in the Upper

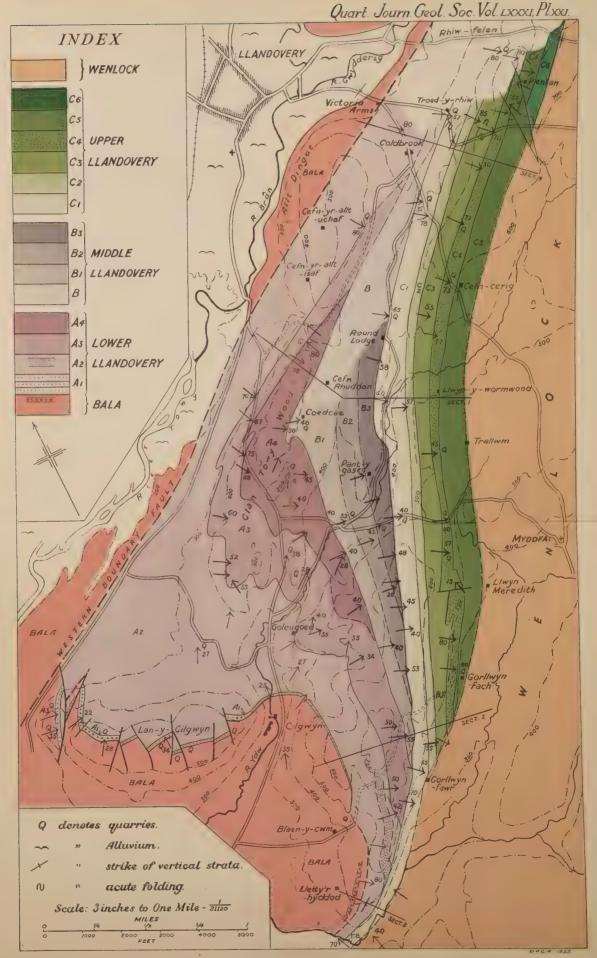
Llandovery case. See Appendix I & Appendix II.

3. Penlan (pp. 75, 80-83, 85). On the earlier pages the rocks are referred to the Lower Llandovery in the Catalogue, but on p. 85 to the Upper Llandovery. The fossils are now in the Upper Llandovery case. Under this name three localities are recorded on the tablets: namely, (a) road-quarry, (b) field-quarry, and (c) lead-mine. See Appendix II, where these localities are discussed.

EXPLANATION OF PLATE XXI.

Geological map of the area south-east of Llandovery, on the scale of 3 inches to the mile, or 1:21,120.

[For the Discussion, see p. 414.]



Geological Map of the Area South-East of Llandovery.



12. The Llandovery Rocks of Garth (Breconshire). By Gerald Andrew, M.Sc., F.G.S. (Read March 11th, 1925.)

[PLATE XXII-MAP.]

CONTENTS.

		Page
I.	Introduction	389
II.	Stratigraphical Description	390
III.	The Relation of the Different Divisions A, B, & C to	
	the Contiguous Strata	400
IV.	Structure of the District	401
V.	Summary	401
VI.	Correlation and Age of the Rocks	403
VII.	Conclusions	404

I. Introduction.

The area described in this paper is shown on Sheet 196 (uncoloured edition) of the 1-inch Ordnance Survey map, and on Sheet 56 S.W. of the (Old Series) 1-inch Geological Survey map, and also on the following 6-inch maps:—Breconshire, viii N.W., N.E., S.W., S.E.; x N.E., S.E.; and xi N.W., S.W.

The district lies north-west of the Irfon, a tributary of the Wye, and mainly in the basin of the Chwefru, which flows south-eastwards through the northern portion to join the Irfon near Builth.

Murchison dismisses most of the tract as containing 'hardly a single bed of solid stone', and compares it with the Radnorshire area, where the 'Upper Silurian' lies, without the intervention of the Caradoc and Llandeilo groups, on the 'Cambrian'. The rocks of Pen cefn-ty-mawr, Allt-y-clŷch, and Dol-y-fan are definitely referred to the 'Cambrian'. His plate (facing p. 346) illustrates this arrangement, as do also the map and section. In 'Siluria' (5th ed. 1872) the strata west of the previous boundary-line of the 'Lower Silurian-Cambrian' were included as 'Lower Silurian'.

The area was first surveyed by the officers of the Geological Survey, W. T. Aveline & Andrew Ramsay, and the map was published in 1850. The section (Sheet 5, Sect. 1), on the scale of 6 inches to the mile, shows the relationships of the Wenlock, 'Tarannon' (Pale) Shales, and Upper and Lower Llandovery. The occurrence of 'sandstones and shales with fossils distinct from those of the Upper Llandovery, Rhynchonella angustifrons, Atrypa marginalis, Pentamerus undatus, Petraia sp.' is recorded. The Upper Llandovery is described as a thick bed of 'coarse sandstone with Pentamerus oblongus, Petraia subduplicata, and large tuberculed Encrinite rings.' From the map we learn that the rocks on Garth Bank were assigned to the Lower Llandovery

Series, but no base-line is drawn along the summit that forms the

Wenallt-Ciliau ridge.

The only area that can be closely compared is the Llandovery district, and one area in some respects supplements the other. By the courtesy of Prof. O. T. Jones, an opportunity has been afforded to me of seeing the ground under his guidance, and Prof. Jones has also very kindly accompanied me over the greater part of the area described in this paper.

II. STRATIGRAPHICAL DESCRIPTION.

The rock-succession is as follows:—

	0	ral Succession. Thickness				
Warran	Степе:	Blue and grey mudstones, with				
WENLOCK.		Cyrtograptus murchisoni.				
	Cd.	Pale olive-green and purple mud-	1000± ?			
	Cc.	Grey sandy mudstones	80			
Upper Llandovery. C.	Cb.	Greenish gritty mudstone, conglo- meratic in the south: Penta- merus oblongus	50-80			
	Ca.	Olive-green mudstones, conglomeratic in the south: P . $oblongus$	130			
Unconformity.						
MIDDLE LLANDOVERY. B.	В.	Olive-green, hard, poorly-cleaved mudstones: Monograptus deci-				
		piens	200 (?)			
Unconformity.						
	Ac.	Sandy mudstones	500			
	Ab.	Micaceous olive-green mudstone, with thin grits in the south	950			
LOWER LLANDOVERY. A.	Aa.	Dark-grey mudstone, with thin gritbands in the south. At the base massive well-jointed blue grit, conglomeratic in the south, passing northwards into soft, orange-				
		weathering, grey mudstone	380			
Bala.		Blue-black sandy mudstones and sandstones.				

Bala Rocks.

The strata which are assigned to the Bala formation consist in the south of fairly soft dark-blue mudstones. They are somewhat sandy in occasional streaks and bands.

Near the junction with the Llandovery in the quarry (Cwm Clŷd) (*1) on the north-east side of Garth Bank the mudstone

¹ The numerals in parentheses preceded by an asterisk, throughout the paper, refer to the locality-numbers on the map (Pl. XXII).

yielded Dayia sp., Eglina sp., Plectambonites cf. quinque-costatus, Pl. thraivensis, Staurocephalus sp., and Encrinurus sp.

The mudstone is poorly cleaved, owing probably in the main to the grain of the rock, and its weathered surfaces usually present a pillowy appearance. The mudstone forms large ellipsoids, the concentric coats of which break off in a manner similar to that which obtains in exfoliating and 'onion-weathering' basalts. This type of sediment shows no bedding-planes, but occasionally irregular sandy streaks are visible, and small brown specks are scattered through it. The sandy streaks show that the rock is much contorted and 'packed'.

When followed along the strike, the arenaceous content increases, and on the ridge north-west of Pen-y-banc the rock can best be described as a sandy mudstone. In the road passing north of this ridge of Cribarth, an outcrop (*2) has yielded a few distorted fossils, including Christiania tenuicincta. On the top of the Wenallt, still farther north, the beds immediately below the base of the Llandovery are sandy grits with interbedded, fine-grained, hard, dark-blue mudstone. These contain some thin calcareous bands, which yielded Rafinesquina corrugatella (*4), Atrypa marginalis, and Rafinesquina siluriana (*5).

Near Pont-ar-Dulas Bala mudstones of the type described as occurring on Garth Bank have furnished a typical Bala fauna, of which the following have been identified:—Plectambonites cf. thraivensis, Pl. papillosus, Pl. cf. quinquecostatus, Cybele sp., Encrinurus multisegmentatus, Pterygometopus cf. brongniartii,

and Remopleurides sp.

On the Wenallt, immediately below the 'basal grit' of Aa, a dark-blue mudstone yielded Glyptograptus cf. persculptus and Mesograptus cf. modestus var. purvulus (*3). Continuing along near the base of the Llandovery Series, the interbedded grits and mudstones appear to form the main mass of the southern end of Ciliau.

From Pen-rhiw-dalar northwards the Bala has yielded no fossils. The grits are traversed by small-scale folding with a northward pitch, the effect of which is to cause the outcrop to run transversely to the general strike of the rocks. The cleavage-planes are widely separated, and appear to divide the mass of the rock into lenticles, which are surrounded by sheared mudstone, so that the rock presents the appearance of an augen-gneiss. The lenticles are usually about 3 to 10 inches long, the average dimensions being 4×8 inches.

North of Lan Fach the sediments become progressively finer, and are well-cleaved mudstones or, near Cwm Fadog, slates without the concretionary structure or the sandy stringers. From Ciliau to the north-east the strike is east-north-easterly parallel to the ridge, with nearly vertical dip. The blue-black cleaved slate of Cwm Fadog is seen in the road north of the farm, much

contorted and presenting a schistose sheen on the irregular cleavage-

surfaces.

These beds are modified, when seen in the stream flowing north of Llanafanfawr, to grey flaggy mudstones with thin bands of bluer mudstone. This, in the Chwefru section on the north, is characteristic of the succession above and below the Allt-y-Clŷch conglomerate. This deposit, which forms the striking feature of Allt-y-Clŷch, is a coarse conglomerate, about 140 feet thick and 475 feet below (upstream) the base of the Llandovery. The strike is north 50° east, and the dip is vertical.

On the northern bank of the Hirnant no other rock of the Bala succession has been found exposed above the conglomerate, which appears to have masked its higher neighbours by a considerable

depth of scree-material.

The graptolites, Glyptograptus cf. persculptus and Mesograptus cf. modestus var. parvulus, which were found in the beds underlying the basal grit of the Wenallt, are those usually associated with the basal zone of the Valentian. The position of the graptolites, which were found together, is about 20 feet (stratigraphically) below the grit which is taken as the base of the Llandovery Series.

If one accepts the view that the occurrence of these graptolites places the containing sediment in the Valentian, then the base-line of the Valentian is drawn in the middle of a uniform series of mudstones, which otherwise contain Bala genera and are thus united with the underlying sediments of Ordovician age. The lithological break, and, therefore, the break in the continuity of physical conditions, is marked by the superposition of the grit that follows these mudstones, and is the natural base of the conformable succession which follows and which is undoubtedly Silurian. The incoming of the fauna of the basal zone of the Silurian preceded in this area the alteration of physical conditions.

Lower Llandovery (A).

The rocks attributed to the Lower Llandovery, are divisible into three groups (Aa–Ac).

The typical succession is that displayed on Garth Bank and

Commin Coch, where the groups are most easily recognized.

Ac. Hard, grey, sandy, thickly-bedded mudstone, irregularly cleaved, with softer, dark-blue, finer-grained mudstone at the base.

Ab. Olive-green, slightly mottled, tough, micaceous mudstone, with thin jointed gritty bands.

Aa. Basal group. Thinly-bedded, blue-grey, flaggy mudstones, with well-jointed grit-beds, 4 to 6 inches thick. Dark-blue sandy mudstones, with blue grit-nodules and blue grit-bands.

Grey-blue massive grit, passing southwards into a conglomerate; thinning northwards.

(Aa) Basal Group.—The Llandovery sediments, like those of the Bala Series, are extremely variable. It is usually convenient to trace the variation northwards.

On the west side of Garth Bank, the section in Garth House Quarry is, in descending order, as follows:-

Thickness in Interbedded blue, well-jointed grits and shaly layers seen for	30
Conglomerate of well-rounded pebbles, and small boulders of	
vein-quartz, microgranite, etc.	6
White conglomeratic grit	5
Conglomerate similar to the one above	8
Pale greenish-grey grit	3
Blue pebbly limestone with, in places, a thin ironstone-band	
at the base	$0\frac{1}{3}$
Total seen	$52\frac{1}{3}$

These overlie the Bala mudstone, with a sharply defined boundary. The overlying Llandovery deposit is quarried away, and the actual junction is usually obscured by scree and soil.

The Cwm Clŷd quarry, farther north, shows a similar succession, except that the base of the Llandovery is formed by a massive grey-blue grit, which has replaced the conglomerate described above, the latter being last seen at a point half-way between the two quarries. The upper surfaces of the grits are rippled; worm-tracks are also found, but no other fossils. The Bala Series has yielded the fauna recorded on p. 391 about 1 to

4 feet below the junction.

North of Garth Bank the grit is displaced eastwards by a fault, and is found having a nearly vertical dip in the quarry near Pen-ybanc. Here the basal grit is a greyish-blue, clean-jointed massive grit, with a few pebbles of vein-quartz. It weathers to a brownish porous rock, which presents a 'pepper-and-salt' appearance, caused by the decay of the argillaceous content. The junction with the Bala is again seen. Between the dark blue 'onion-weathering' Bala mudstones and the basal grit is a band of white quartzite about an inch and a half thick, with nodules of pyrites that show radiating structure. The junction is quite sharp on both sides of the quartzite.

The basal grit runs northwards, striking north 18° east, and dipping 50° to 60° eastwards along the eastern (dip) slope of Wenallt; it gradually becomes more argillaceous, being striped with darker, more easily weathered bands. A similar change takes place in the overlying beds, and nearer Wenallt the strata are blue,

sandy, well-cleaved mudstones, devoid of grits.

The northernmost exposure of the basal grit is in the quarry north of Lan Fach, where it is overlain by alternating mudstones and sandy bands, similar to the Bala rocks on Ciliau, and these are, in turn, succeeded by soft, grey, orange-weathering mudstones, which break up into spindle-shaped pieces showing a roughly rectangular cross-section.

Farther north, near Cwm Fadog, the base of the Llandovery Series is formed by the alternating series described above, and is succeeds. overlain by dark-blue well-cleaved Bala rocks. These are succeeded

by white-weathering, orange-stained, greenish mudstones, which are poorly bedded and break up into spindles. The mudstone contains a few gritty bands, but the alternating series seen in the

stream on the south cannot be recognized in the section.

From here northwards the orange- or buff-weathering mudstones are seen, overlying generally sandy and blue-banded grey mudstones and blue mudstones of Bala type. They are followed by blue mudstones with thin flaggy bands of hard mudstone, gritbands, and grit-lenticles, seen in the road from Llanfanfawr to Llanfihangel Bryn Pabuan.

North of the Chwefru the basal beds are not seen. On the south-eastern slope of Allt-y-Clŷch a mass of scree and soil masks the underlying rock, and the only exposures are near the Hirnant on the north and south sides of that stream. The mudstone met here is different from any hitherto described: it is comparable with the northern development of Ab, and this occurs only 300 feet above the Allt-y-Clŷch conglomerate, which itself is about 450 feet below mudstones of Llandovery type in the Chwefru.

North of the Hirnant there are no exposures of beds immediately underlying the 'Paste Rock' (Cd), and the ground is covered by

thick glacial deposits and alluvium as far as the Wye.

The southernmost exposure of the upper part of Aa is seen in the path from the southern end of Garth Bank to the summit. In this path are seen dark-blue flaggy beds, with blue grit-nodules and bands from 2 to 4 inches thick. A noticeable hollow along the western side of the hill is made by these rocks, which interpose between the basal beds and the beds of Ab that form the highest ground. Indications of the type of sediment are given by the débris from rabbit-burrows, but the solid rock is not exposed.

An almost continuous succession is exposed near Pen-y-banc, where the upper part of Aa is composed of grits with interbedded

hard mudstones, very similar to those in Cwm Clŷd.

South of Pentre-llwyn-llwyd, in a stream and in the road running through the village, these blue mudstones are found with tough blue grit-lenticles and bands, occasionally weathering with a pronounced orange staining. The mudstones are sandy and roughly cleaved, and the uppermost beds are much softer.

Near the cross-roads north of Pentre-llwyn-llwyd, and at Llanafanfawr, a succession of dark blue-grey mudstones with dark-blue grit-lenticles and deep 'navy-blue' flaggy bands is exposed, followed by a soft, dark-blue, spindly mudstone with brilliant orange weathering. These beds are not seen north of the Chwefru.

(Ab).—Following on the mudstones of Aa is a considerable thickness of hard micaceous mudstones, forming the features of Garth Bank, Commin Coch, and Lan Ystenu.

On these hills the clearest division between Aa, Ab, and Ac is possible, because this mudstone group is tough and distinctive in appearance between two comparatively soft series.

On Garth Bank the group consists of hard, massive, olive-green,

micaceous mudstones containing 'nests' or patches, arranged parallel with the bedding, of flakes of a white mica. In this mudstone are gritty bands, which are greenish (like the matrix), but coarser in grain. These give the only clue to the bedding in an otherwise structureless rock. Rottenstone nodule-bands occur, showing concentric structure. The mudstone is very poorly cleaved, having a rough surface of division in the direction of cleavage common to the district. Both gritty beds and mudstones are occasionally mottled with darker patches measuring about 4 inches in diameter. This mottling is irregular and roughly spherical, disseminated through the mass of the rock, and is a coloration induced at, or immediately after, the time of deposition. The mudstone becomes much finer in grain and softer on the north, and is grey with a tendency to be greenish, weathering with a palebuff stain. The harder type reaches the northern slope of Lan Ystenu, but from there northwards it rapidly degenerates into a soft, slightly sandy mudstone devoid of persistent grit-bands, which are replaced by nodules and lenticles. Where a good exposure occurs, the mudstone is seen to have a 'pillow' or 'onion' structure. The sandy stringers dip in all directions, and the mudstone has apparently been so crushed in the folding movement as to shatter any trace of bedding.

This division makes the most imposing show on the ground in the south, owing to its toughness and thickness. The apparent thickness, however, is increased on the north, both by lessened dip and by folding. One small syncline at least is indicated on Commin Coch by reversed dips, as also on Lan Ystenu, and in the

Chwefru section further folding is indicated.

The micaceous character is lost about half a mile north of Lan Ystenu. A good section is exposed in the Nant Carai, the beds being here sandy, poorly-cleaved, grey mudstones showing no

particular structure.

In the Chwefru valley a good section of the division is afforded by the stream. Above the orange-stained band, which here forms the uppermost part of Aa, are greenish-grey mudstones, slightly sandy. Near the top, at Dol-y-felin, the mudstone is slightly banded, and contains a few gritty lenticles and thin beds. The grits are greenish-blue, and only the lenticles that occur upstream

from this point exceed 1 inch in thickness.

North of the Chwefru is a large patch of ground without exposures, and no good exposures are found until the road from Llanafanfawr to St. Michael's Church is reached. Between Pisgah and St. Michael's Church is a section in the road of olive-green slightly sandy mudstone, with occasional blue-green gritbands. The grits cross the road with a steady strike and dip, showing that folding in this part is absent. They are well-jointed, and normally between 2 and 3 inches thick. The grits are developed in the upper part of Ab only, and this incoming of grits in the north appears to point to nearness to a land-area north of this point.

Mudstones of this type, in which no grits occur, are seen close to the Allt-y-Clŷch conglomerate in the Hirnant valley, and it is because of the similarity of colour and character that they are

placed in Ab.

The group Ab is sparingly fossiliferous; in the south, on Garth Bank (*6, *7), these mudstones yielded Atrypa marginalis, Meristina cf. crassa, M. subundata, Plectambonites undulatus, Stricklandinia cf. lens, and Whitfieldella angustifrons. Farther north (*8, *9) a single specimen of Plectambonites duplicatus was found, in addition to the above. The group does not yield recognizable fossils north of the Chwefru.

(Ac).—The uppermost beds of the Lower Llandovery have proved to be the most easily traceable, the least variable, and the

most fossiliferous of this thickness of mudstone.

The sediments are similar throughout the whole thickness of the division, with minor changes from a soft, poorly-cleaved, thickly-bedded, dark blue-grey mudstone in the lower half, to a hard, grey, slightly sandy, poorly-cleaved, thickly-bedded mud-

stone in the upper part.

The cleavage affecting the mudstone is poor and irregular, dividing the rock into disc-like masses, resembling two saucers placed together with their rims in contact. This appears to be a modification of the 'pillow'-structure of the Bala mudstone, concentric weathering being found in the larger masses. The bedding is thick and is not seen, except in large exposures, where strings of calcareous nodules, now weathered or decomposed to rottenstone, or to a brown ferruginous powder, show the dip as well as bedding-planes from 3 to $4\frac{1}{2}$ feet apart, and, rarely, narrow bands of paler, very slightly more sandy mudstone, from 1 to 2 inches thick.

Where the mudstone is more sandy, a greenish tinge is noted, whereas in the finest-grained mudstone, without sandy streaks, the

colour is a darker blue-grey.

The lower part of Ac is first seen in the quarry near Ty-cochbach (*11) on the northern end of Garth Bank, and may be traced easily northwards by the pronounced hollow immediately behind the feature which the uppermost part of Ac makes. This locality yielded Atrypa marginalis, Barrandella undata, Bilobites sp., Dalmanella sp., Leptæna rhomboidalis, Merislina subundata, Orthis sp., Plectambonites undulatus, Pl. duplicatus, Pl. mullochensis, Pl. tricostatus, Pl. sp., Scenidium ef. woodlandense, Scenidium sp., Stricklandinia lens, Strophomena antiquata, Strophomena sp., Triplesia insularis, Calymene sp., Lichas sp., Favosites fibrosus, Petraia sp., and Climacograptus ef. scalaris.

The upper part of Ac is first met with on the southern end of Commin Coch, in the road (*12), where, in addition to the forms enumerated in the preceding paragraph, *Plectambonites scissus*,

Rafinesquina sp., Encrinurus punctatus, Dictyonema sp., and Monograptus atavus were obtained. It is overstepped on the south by the Upper Llandovery (C) on Garth Bank. From this point northwards to Bwlch-y-Garth the slightly harder mudstone

forms the prominent feature mentioned above.

North of Commin-y-Garth the whole group consists of a greenish hard mudstone, with rottenstone bands, thickly-bedded, cleaved as before, the mudstone having a peculiar 'saccharoidal' appearance, like that of a dull chalcedony. This type is exposed near St. Michael's Church, and between that point and the northern end of Commin-y-Garth.

The fossils occur mainly in the southernmost portions of the outcrop. The number of species and the size of the specimens diminish northwards. In the locality near Ty-coch-bach (*11), the specimens appear to have been well nourished, and a large variety is found. On the north, a little above this in horizon (*12), a similar profusion of fossils is noted, but the forms are somewhat smaller, and poorly developed individuals are common.

Northwards again (*13, *14) a further diminution in the number of forms and in their size is seen, and north of these places the fauna in all cases is poor. At (*15) the commonest forms are *Dalmanella* sp. and *Scenidium*, and few others are found without long search. The attenuation of the fauna continues, and only a very few and ill-preserved forms are obtained at (*18).

The Middle Llandovery (B).

There is a small development of a hard greenish-grey, cleaved mudstone exposed near Cefn-y-Coed (*20), containing fossils distinct from those found in the Upper and Lower Llandovery. The lithology also is distinct from both Upper and Lower Llandovery, being intermediate in type and colour between the hard grey mudstone of Ad and the soft olive-green mudstone of Ca.

The junctions of the upper and lower limits with the over- and underlying beds are not exposed, and the question of conformity can only be settled by comparison of the succession here with the

nearest development of these beds.

The following forms were found:—Monograptus decipiens, Plectambonites sp., Favosites fibrosus, Dalmanella sp., and Cystid plates. The fauna is poor and badly preserved.

The Upper Llandovery (C).

The beds of this upper group are as variable as those of the Lower Llandovery Series. It is most convenient to treat Ca-Cc together first, and then Cd.

The lower part (Ca-Cc) consists, in the main, of a greenish soft mudstone, with admixtures of more or less coarse-grained

material. Rarely does one find a true grit, except at the base, and all the harder bands consist of well-rolled quartz-pebbles and grains in a soft mudstone matrix. One lenticle of shelly limestone has been found (*26). The fullest sequence is seen east of Ty'n-y-coed, and is as follows:—

Cc. Grey, hard, spindly mudstone, with few fossils.

Cb. Hard conglomeratic and gritty mudstone.

Ca. Olive-green mudstone, conglomeratic in the south. Basal grit or quartzite, yielding Pentamerus oblongus.

The southernmost exposures of the Upper Llandovery (on Garth Bank) are of conglomeratic mudstone with *Pentamerus oblongus* and *Atrypa reticularis*, succeeded by a mudstone resembling Cc, here unfossiliferous. It is not possible to recognize the subdivisions Ca and Cb on Garth Bank. This conglomeratic mudstone passes laterally northwards into mudstone in which the arenaceous content is less.

South of Ty'n-y-coed no basal grit is seen, but the basal grit is a persistent feature in the north, as far as Commin-y-Garth. The lower mudstones are not conglomeratic north of Ty'n-y-coed, and are fine-grained blocky mudstones, with a tendency to mottling. They are soft, except near Cefn-y-coed (*31); they yield at this point Bilobites bilobu, Lingula sp., Pentamerus oblongus, Phacops ef. elegans, and Glyptocrinus stems. These mudstones are traceable along the strike to Commin-y-Garth, north of which they are not seen, being overlapped by the base of Cd.

The hard conglomeratic or gritty mudstone of Cb accounts for a decided feature along the eastern side of Commin Coch and a little to the north. The mudstone is almost an argillaceous grit, and is used locally as a building-stone and road-metal, but it soon breaks down under mechanical abrasion, the matrix being essentially muddy. The band thickens from south of Ty-coch-bach as far as the point where it crosses the Gwinneuddu. From the quarry north of this crossing the following were obtained:—

Atrypa reticularis, Barrandella cf. undata, Hebertella protensa, Meristina sp., Orthis calligramma var., Pentamerus oblongus, Stricklandinia sp. cf. lens, Petraia sp., and Favosites sp., with crinoid-stems (*23); and on the north (*24) Stropheodonta arenacea was found, with Barrandella undata and Pentamerus oblongus.

Near Ty'n-y-coed (*26) there is a local development of limestone at the base of Cb, from which the following were obtained:— Atrypa marginalis, A. reticularis, Barrandella cf. undata, Brachyprion sp., Dalmanella sp., Hebertella protensa, Orthis sp., Pentamerus oblongus, Platystrophia biforata, Plectambonites mullochensis var., Pl. cf. duplicatus, Pl. cf. undulatus, Pl. scissus, Pl. spp., Rafinesquina sp., Stricklandinia sp. cf. lens, Orthoceras sp., Favosites porosus, F. fibrosus, Petraia cf.

elongata, Petraia sp., and Calymene sp.

The bed thins rather rapidly northwards, but appears to be still

important as a feature-forming horizon, especially where the outcrop is extended by folding east of Ty'n-y-coed. This bed is last seen in the road west of Hafod-yr-ancre; but its position in the sequence appears to be taken by a tough, though non-conglomeratic and unfossiliferous mudstone north of the Chwefru, which is seen on the southern part of Commin-y-Garth as a small feature along the dip-slope, until it is overlapped by Cd.

The mudstone of Cc is not usually well exposed. It crops out at Ty-coch-bach, east of Ty'n-y-coed, and near Hafod-yr-ancre. It is a grey spindly mudstone, not so fine-grained as the lower (Ca) mudstone, and rarely yields *Pentamerus oblongus* and *Atrypa*

reticularis.

Organic remains as a whole are not abundant, except very locally, and the fauna is a poor one.

The uppermost beds of the Upper Llandovery (Cd) are almost devoid of organic remains. In the region south of the Chwefru, the base is drawn at the base of a blue flaggy band, sometimes hard mudstone, which appears to be a persistent horizon, extending northwards from Garth Bank to north of the Chwefru. There is no discordance observable, either above or below this band, and it is followed by pale yellowish or olive-green mudstone, in places mottled, with occasional concretions of rottenstone in the south.

North of Hafod-yr-ancre these mudstones thicken considerably. Exposures are not numerous, and are lacking at the base of the series between Commin-y-Garth and Newbridge, and the base-line

drawn is approximate.

North of Commin-y-Garth these mudstones develop purple staining in bands, and occasional green grits make their appearance; but the bands appear to be impersistent, and of no value as aids to mapping. The purple-stained mudstone is usually mottled

with green.

Near Hafod-yr-ancre, the uppermost beds of these mudstones have yielded Monograptus priodon and M. crenulatus (*40); here a gradual unbroken transition is seen up into the Wenlock Series, from which Cyrtograptus murchisoni has been obtained at this point (*41), accompanied by M. crenulatus, M. priodon, Retiolites (Gladiograptus) geinitzianus, and M. capillaceus. These pale mudstones (the 'Paste Rock' of Sedgwick and the 'Tarannon Pale Shales' of the Geological Survey) appear to be a transition between the Upper Llandovery of arenaceous-shelly facies and the Wenlock of graptolitic facies.

The base-line of the Wenlock Series has been drawn to include in that formation the mudstones which are predominantly thinbedded and striped, and separating the blocky, even-grained, and mottled types as Cd. This line may possibly have no stratigraphical significance, and may delimit a facies only; but no alternative was open to me in the district surveyed. The transi

tion, though complete, in the central region is rapid.

Wenlock.

The Wenlock beds are characteristically blue, laminated, shaly, calcareous mudstones, weathering to a pale-buff colour. They contain the graptolites mentioned above. The lowest beds are most distinct from the mudstones of Cd in the southern part of the district, where they consist usually of grey gritty beds seen in Erw-neuadd farmyard, resting on very dissimilar mudstones of Cd with a sharp boundary.

In the south, near Garth Bank, the base of the Wenlock Series is obscured by soil, and the only localities exposed yield fossils which appear to belong to higher beds, possibly the uppermost parts of the zone of *Cyrtograptus murchisoni*, or the base of the

following zone (*34) and (*35).

III. THE RELATION OF THE DIFFERENT DIVISIONS A, B, & C TO THE CONTIGUOUS STRATA.

The base of the Silurian is sharp in the southern part of the area, and an abrupt change in lithology marks it. Two graptolites usually associated with the base of the Valentian occur below the break, and suggest that the Lower Llandovery succeeded the Bala with very little time-interval, since the fauna enters in an apparently continuous and homogeneous series. There is considerable lateral variation in the Bala, and abrupt lithological changes of sediment in the vertical succession indicate no more than a change of the amount and nature of the supply, rather than any lapse of time, unrepresented by sediment.

The relation of the middle group B to A is one of unconformity, comparison with the succession at Llandovery demonstrating the absence of some 500 feet of the lower division. The relationship of C to B is probably one of unconformity, although no exposures occur on the line of junction, and there is no direct evidence to that effect. The rapid overstep of the base of C suggests un-

conformity.

The relation of C to A is one of unconformity at every point where they are in contact. In the south, near Ty-coch-bach, the actual junction is visible (*11), and is seen to be perfectly welded, giving the impression of a conformable succession.

Elsewhere the upper mudstones of Ac are overlain by a quartzitic bed, and these, being much harder than the overlying mudstone, form a feature that gives a misleading impression of conformity, running northwards from Commin Coch to Commin-y-Garth.

So far as can be ascertained, there is a continuous and complete succession from Ca to the Wenlock; the passage of Cd to the

Wenlock is complete.

The overstep of the Upper Llandovery and of the Wenlock on to continuously lower horizons is steady in either direction from a point on the line of widest outcrop, which line appears to be the axis of a trough.

IV. STRUCTURE OF THE DISTRICT.

The structure of the district is simple. In the south the Llandovery Series dips steadily south-eastwards under the Wenlock, at nearly 90°. Northwards this dip decreases, and minor folding has taken place, thickening the outcrop of A considerably, and affecting locally beds of Ca-Cd (Commin-Coch, Lan Ystenu, and east of Ty'n-y-coed).

Farther north, in the main Chwefru basin, owing to lateral change in the sediment, there is a softer mudstone in Ab, and there has been much small-scale folding in these beds; the effect can only be estimated approximately, since the mudstones are

structureless, and have yielded to stress by packing.

Folding takes place in the upper part of the Upper Llandovery Series (Cd) north of the Chwefru, with gentle dips. Such folds are not mapped, as there is no band or horizon that will serve the

purpose of demonstrating the folds.

The faults that occur within the area are, with one exception, of little importance. The faults affecting the basal grit appear to be small dislocations due to the behaviour of the sediment under compression. Packing in the surrounding mudstones is paralleled by fracture in such deposits as grits. The movement was probably of the nature of a 'tear'-fault, as is obviously the case in the fault between Pen-y-bane and Ty-coch-bach, shifting vertical beds.

The only important fault is that drawn as the western boundary of the Lower Llandovery in the north and along the eastern front of Allt-y-Clŷch. This is considered to be the only adequate hypothesis explaining the disappearance of the lower beds of A against the Bala, before overstep by Cd hides them.

From a minor fold near the farm Cwm Gwinneuddu (locally spoken of as Pen-rhiw-môch) the elements of folding are as follows:—The axial plane strikes north $43\frac{1}{2}$ ° east, and dips north-eastwards at $52\frac{1}{2}$ °. The pitch is 18° in a direction north 34° east. This fold is an anticline, and the eastern limb is the steeper.

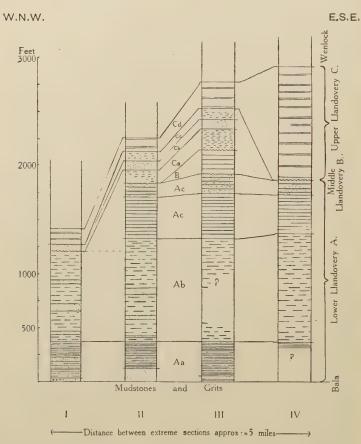
A small syncline in the Chwefru, a little upstream from Dolyfelin, gives the following results:—The axial plane strikes north 56° east, and dips at nearly 90°; the pitch is 19½° in a direction north 57° east.

V. SUMMARY.

Three main divisions of Llandovery strata have been recognized:—

- (C) Mudstones with a few conglomeratic beds, becoming fine in the north, with Pentamerus oblongus, Atrypa reticularis, etc.
- (B) Greenish mudstones containing a poor fauna; Monograptus decipiens.
- (A) Mudstones with subordinate grits, fossiliferous in the upper part, which contains Barrandella undata, Plectambonites spp., and Monograptus atavus.

Vertical sections illustrating the variation in thickness and in lithology of the Llandovery rocks of the Garth district.



[Section I is through Garth Bank; II, through Wenallt—Commin Coch; III, from Cwm Fadog to Hafod-yr-ancre; IV, through Allt-y-Clŷ south-east towards the Wye.]

These Llandovery beds are overlain by shaly mudstones of Wenlock age yielding *Cyrtograptus murchisoni*, and are underlain by mudstones of Bala age containing a poor fauna of shelly facies.

The succession dips generally south-eastwards, and is variable in

lithology.

The fauna indicates for A & B a Lower Birkhill age, and for C an Upper Birkhill age, and this is conclusively proved by reference to the Llandovery area.

The Llandovery Series follows on the Bala with apparent conformity in the north, but the change is abrupt in the south, and

suggests a physical break of some suddenness.

A is followed by B unconformably, and B is probably followed by C unconformably. These unconformities are demonstrated by

comparison with the fuller succession at Llandovery.

There appears to be a complete passage from the base of C into the Wenlock, but an abbreviated succession is seen in the south, where there appears to be a break between Cd and the Wenlock Series.

VI. CORRELATION AND AGE OF THE ROCKS.

Of two neighbouring areas, recent descriptions of which are available, only one allows of detailed comparison. The Rhayader district, differing in facies and in lithology from the Garth district, is difficult to compare closely. Lithologically, a rough comparison is possible. The Cerrig Gwynion Grits appear to be represented by the basal grit of Aa, while the Dyffryn Flags are closely resembled by the remainder of Aa and Ab, especially in the northern part of the area. Ab, with Monograptus atavus and Climacograptus scalaris, will correspond to the lower portion of the Ddol Shales, up to a little above the zone of Monograptus cyphus.

The Middle and Upper Groups cannot be closely compared

directly with Rhayader deposits.

The other district with which comparison is available renders clear many points that would remain obscure in the absence of a detailed knowledge of the Llandovery Series. A correlation which is based on both faunal and lithological grounds is possible, especially with regard to the Lower Llandovery rocks.

The groups described in this paper under the designations Aa, Ab, & Ac appear accurately to represent A_1 , A_2 , & A_3 of the

southern part of the Llandovery area.

In the centre of the Garth district B occurs, and resembles the

uppermost division of B near Llandovery (B₃).

The Upper Llandovery sediments cannot be correlated with any accuracy. The lower part of the succession in the Llandovery district would, however, appear to be unrepresented near Garth, as that part which occurs here presents a complete sequence up into the Wenlock Series.

VII. CONCLUSIONS.

After the change of conditions which terminated the Bala succession, deposition commenced in a basin, or probably a 'bay,' the southern limit of which could not have been far south of Garth Bank, and the northern limit of which was probably not far north of Newbridge. Subsidence and deposition were steadily continued in Lower Llandovery times. The absence of any trace of Lower Llandovery sediments east of this district, where the Upper Llandovery lies unconformably on the Llandeilo Flags (Carneddau), renders it improbable that the eastern margin of the basin was more than a few miles east of Garth. The supply of sediment appears to have come from the south or south-east in the south, but the middle division (Ab) coarsens slightly in the north again. Elevation took place after the deposition of Ac, with erosion. This elevation could not have been accompanied by much warping since, in the centre of the district, the Lower Llandovery deposits appear to have been worn down to almost a definite horizon. Then followed deposition of B, preserved only in what must be considered as the centre of the basin.

The sediments of C indicate the approach of the general subsidence, during which a vast tract of land on the south-east was submerged. The accurate correlation of the Upper Llandovery sediments in this area with those of other areas is not possible at present. The lithology is variable, and indicates a similar kind of subsidence, and the direction of supply of coarser sediments was the same as that which obtained during the deposition of the Lower Llandovery rocks. This Upper Llandovery sea appears to have been limited northwards within the area, but extended a

long way to the east.

Following upon Ce, the downward movement inundated a large area on the north as well as the eastern shores of the basin, and the pale mudstones of Cd were deposited. These are now represented in the east by at most a thin band, and a movement similar to that which occurred after Lower Llandovery time must have swept these mudstones off the basal phase (*Pentamerus-oblongus* Beds) before the deposition of the Wenlock in the Carneddau area. They were also limited towards the south, but

the basin appears to have extended northwards.

The fauna of the area is poor and of the shelly facies. A few graptolites, however, have been found in the Llandovery rocks, and more frequently in the Wenlock. The district generally seems to have been in that part of the Llandovery sea which was in receipt of a heavy supply of sediment, borne by moderately strong currents and producing the sandy mudstones that we now see. In these muddy waters the fauna of the shelly facies seems to have found considerable difficulty in flourishing, and graptolites would also appear to have found the environment uncongenial.

¹ G. L. Elles, Q. J. G. S. vol. lvi (1900) pp. 370 et seqq.



The shelly fossils obtained show a variation parallel with the sediments that contain them. In some of the grit-bands of Ab numerous fossils are encountered. These may have been carried to the spot where they now occur by the currents which brought the grit. In the mudstones fossils are much rarer. In Ac the forms found in the south are more numerous, and are much larger than in exposures on the north. A general decrease from Garth Bank northwards is observed in the number of species, the number of individuals of any species, and the size of these individuals. The same condition appears to hold good in the Upper Llandovery Series.

The area was folded along north-east and south-west lines, in common with the rest of Wales and the border country. A general decrease in the severity with which the movement has affected the strata is noticed as one travels upwards in the succession; it is also found in the north that the dips lessen, and folding has

become more gentle.

Cleavage appears to affect all fine-grained members of the lower or middle divisions. The members of the upper division are rarely cleaved, but, when gritty, are well jointed. The uppermost 'Paste Rock' is not cleaved in the south. In the north, south of Newbridge, the mudstone has a definite structural plane dipping at a high angle; but, in the absence of any reliable evidence as to bedding, this cannot be considered to be cleavage. The structure, however, resembles cleavage in every particular, and is transverse to the mottling in the purple and green bands.

One interesting point that remains to be noted is the tendency of sediments to be pale olive-green in colour north of a line from Erw'r ddalen to the Cross-Roads Post-Office. The beds of Ab and Ac turn green, and in colour show great resemblance to those

of Cd in this part.

In conclusion, I have to acknowledge much assistance both in the field and in connexion with the fossils from Prof. O. T. Jones. He has named all the fossils, with the exception of a few from the Wenlock Series, and has conducted me over the Llandovery area for the purposes of comparison. I am also indebted to Mr. S. H. Straw for assistance in the naming of the remaining Wenlock graptolites, with one exception, the erroneous name of which Dr. G. L. Elles has very kindly corrected for me.

EXPLANATION OF PLATE XXII.

Geological map of the neighbourhood of Garth, on the scale of 3 inches to the mile, or 1:21,120.

Locality-numbers.

Bala: *1 to *5.
Lower Llandovery: Ab, *6 to *10; Ac, *11 to *18.
Middle Llandovery: B, *19 to *20.
Upper Llandovery: (Ca-Ce), *21 to *33.
Wenlock and Transition Beds: *34 to *45.

[For the Discussion, see p. 414.]

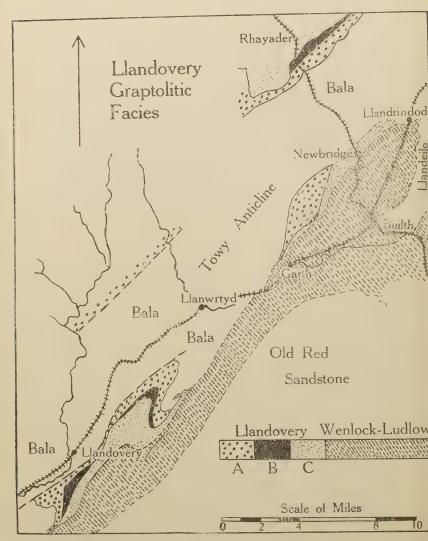
13. The Relations between the Llandovery Rocks of Llandovery and those of Garth. By Gerald Andrew, M.Sc., F.G.S., and Prof. Owen Thomas Jones, M.A., D.Sc., F.G.S. (Read March 11th, 1925.)

While we were engaged in examining the districts described in the two preceding communications, we frequently compared notes upon the succession and fauna. These comparisons appeared to show that during the Llandovery Epoch the geological events in one district were reproduced with some exactness in the other. A closer enquiry revealed, however, certain significant differences between the two areas, and, as both the similarities and the differences throw an interesting light upon the earth-movements which affected these areas during the Llandovery Epoch, we believe that it will serve a useful purpose to bring them to the notice of the Society. The observations upon which the comparisons are based are contained in the accounts of the respective areas, except that some additional facts relating to the northern part of the Llandovery district are recorded in this paper and on the map which accompanies it (p. 408).

Situation.

Both districts lie on the eastern flank of the Towy Anticline, and on the same general line of strike. The rocks belong to the shelly facies, but contain an occasional graptolite. About 5 miles away to the west, the Llandovery rocks of Rhavader and of Ystradffin mark the position of the western flank of the Towy Anticline, but these belong to the graptolitic facies. The axis of that anticline is not situated midway between the eastern and the western Silurian outcrops; it must, in fact, pass within a mile or two west of the base of the Silurian in both the Garth and the Llandovery districts. Its asymmetric position is in accordance with the dips of the strata in the flanks of the fold; the rocks in the western outcrop have a relatively low dip on the average, while in the eastern outcrop they are nearly vertical, and in places are overturned. In each district the Lower Llandovery succeeds the Bala with apparent conformity, and both the Lower and the Middle Llandovery rocks have a restricted distribution. At Llandovery the Lower Llandovery strata gradually emerge from beneath the Upper Llandovery near the Sefin valley, east of Llangadock, and they disappear under that group about 10 miles away to the north-east. After an interval of about 9½ miles. they reappear from underneath the Wenlock and Upper Llandovery almost simultaneously at the southern end of the Garth district, and, remaining at the surface for 5½ miles, pass once more underneath the Upper Llandovery. The Middle Llandovery rocks are confined to the central region of each area. These areas

Map illustrating the relations between the Llandovery rocks of Llandovery and those of Garth.



in North Carmarthenshire and in Breconshire, and the Narberth-Haverfordwest district in Pembrokeshire, are the only districts where the Lower (and in places the Middle) Llandovery Stage is exposed on the eastern or southern flank of the Towy Anticline.

Lithological Variations in the Lower Llandovery Stage.

The variations in the vertical succession of the strata are similar in the two districts: a basement group containing massive sandstones and occasional conglomerates is succeeded by a grey mudstone group almost barren of fossils, which is overlain by a fossiliferous group. The thicknesses of the equivalent groups are closely comparable, but at Llandovery there are about 700 feet of strata representing a higher group which is not found at Garth.

In addition, there are, especially in the lower groups, variations of lithology in the rocks as they are traced along the general strike. In the Llandovery area the basement group is exposed only at the southern and northern ends of the district; elsewhere it is cut out by the western boundary-fault. The grits and conglomerates, which are well developed at the southern end, have almost, if not quite, disappeared at the northern end. In places, an impersistent band of sandstone there separates fossiliferous Bala mudstones from rusty shales lying near, or at, the base of the Llandovery Series. It is not clear whether this sandstone should be assigned to the Bala or to the Llandovery Series, and, where it is not present, the Llandovery shales rest directly upon the Bala shales or mudstones.

The Basement Group, which is arenaceous in the south, becomes argillaceous in the north. A lithological change of precisely the same kind can be traced along the strike from south to north in the Garth district. At the southern end the basement group is very similar to that at the southern end of the Llandovery district; but at the northern end it is a matter of some difficulty to decide where the boundary between the Bala and the Lower Llandovery rocks should be drawn. As at Llandovery, the western boundary appears to be defined by a fault from near the centre of the district northwards.

The Grey Mudstone Group at Llandovery includes in the south of the district numerous beds of hard, micaceous, grey sandstone which are sparingly fossiliferous; these disappear in a mile or two along the strike to the north, and are replaced by barren mudstones. In the Garth district fossiliferous micaceous sandstones form an important part of the corresponding group; but in less than 3 miles they have disappeared, and their place is taken by a uniform series of barren grey mudstone. At the extreme northern end of the district there are indications of a change in the reverse direction, since micaceous sandstones make their appearance once more among the mudstones. In that district the lithological variations thus tend to be symmetrical with respect to the centre of the outcrop.

2 E 2

At least three different explanations of these variations can be

(i) The present outcrops of the rocks do not coincide with the belts within which the conditions of deposition during the Llan-

dovery Epoch were similar.

If a line be drawn through the middle of the Lower Llandovery outcrops from Llandovery to Garth, there is a strong lithological and faunal similarity between the rocks along that line at all those horizons which are represented in both districts. If another line be drawn on the other side of the Towy Anticline from Rhayader to Ystradffin, 6 miles west of Llanwrtyd, the rocks and fauna along it are again closely alike; but there is a great difference between the development on the eastern flank and that on the western flank, proving that lithological and faunal variation proceeded rapidly across the present strike.

Again, a comparison between the Garth district, where a great thickness of Llandovery rocks is present, and the Builth area, where only a small thickness of Upper Llandovery rocks occurs, taken together with the lithology and fauna of the Lower and Middle Llandovery, implies that the coast-line during those epochs

lay not far east of the existing outcrops of these groups.

It is possible that in the Cilgwyn escarpment at the southern end of the Llandovery district, where the outcrop of the Basement Group trends across the general strike, this might account for the changes observed. At the northern end of that district, too, the rocks become coarser-grained in crossing the Cefn-y-Gareg syncline, 5 miles north-east of Llandovery. In the Garth district, however, changes like those at the southern end of the Llandovery district take place in the Basement Group along the strike of the rocks. Moreover, the direction of change in the micaceous sandstones pertaining to the Grey Mudstone Group lies almost exactly along the general strike in both districts.

(ii) The gravel, sand, and mud, introduced at certain points into the Lower Llandovery sea from a land-area lying to the east, were distributed by longshore currents directed from south to north, just as similar materials are drifted northwards at the present day along the west coast of Wales. If this suggested explanation could be proved, it would throw an interesting light on the physical and geographical conditions that prevailed during the Llandovery Epoch.

The indications at the northern end of the Garth district, of a return to arenaceous conditions during the deposition of the Grey Mudstone Group, tell against such a supposition, and it is not

supported by any other evidence.

(iii) It may be suggested that coarser materials were laid down in greater abundance at certain localities along the Lower Llandovery coast-line, owing to spasmodic shallowing of the sea-floor by uplift.

In view of the later history of the area, this suggested ex-

planation appears to be the most probable one.

Movements at the End of Lower Llandovery Time.

At the close of this epoch, uplift of the Llandovery area occurred, attaining a maximum along certain axes lying transversely to the present strike. One of these was in the south, and another in the centre. There may have been a third axis at the northern end of the district, but there is as yet no proof of this. In consequence of these movements the Middle Llandovery rocks overstep the Lower Llandovery at both ends of the southern area and towards the southern end of the northern area, but it is not known whether they overstep these rocks at the other end of that area. In the Garth district the Middle Llandovery rocks rest upon a horizon of the Lower Llandovery at least 700 feet below the top of that group; but, owing to the small extent of the outcrop, it has not been possible to determine whether or no the unconformity is accompanied by overstep.

The Middle Llandovery, and Movements at the Close of that Epoch.

The Middle Llandovery sediments of the two areas are so similar in lithology as to lead to the belief that they were formed under similar conditions, and probably at about the same distance

from the shore-line of the epoch.

Before the deposition of the Upper Llandovery sediments the pre-existing rocks had again been elevated in both districts. At Llandovery elevation took place along three transverse axes, in consequence of which the Upper Llandovery rocks overstep the Middle Llandovery north and south of the central region of both the northern and the southern areas. In the Garth district we note precisely the same relations between the Upper and the Middle Llandovery. During these intraformational movements there were, therefore, three regions of persistent depression: two in the Llandovery area and one in the Garth area—these regions being those where alone the Middle Llandovery rocks are preserved, and where (at Llandovery) the fullest succession of the Lower Llandovery occurs. These regions of depression are situated midway between the areas of elevation, the distance between them being about 6 miles. It is significant that the distance between the Middle Llandovery outcrop in the Garth district and the middle of the outcrop of the same rocks in the northern Llandovery area is 13 miles, or about double that from one region of depression to the other.

There is, consequently, some reason for suspecting that axes of intraformational elevation and depression were, during the Llandovery Epoch, distributed at fairly regular intervals across a line following the present strike, but that some of these are now concealed between Llandovery and Garth beneath the Wenlock shales. This suggestion finds confirmation in the Rhayader area. The

¹ H. Lapworth, 'The Silurian Sequence of Rhayader' Q. J. G. S. vol. lvi (1900) pp. 67-137.

Gigrin Mudstones, which are the equivalents of the Middle Llandovery rocks of Llandovery, are only represented for a distance of 5 miles in the central part of that area (see op. cit. pl. vii); at the western end they are rapidly overstepped by the Caban Group, which is now known to be of the same age as the basal subdivision of the Upper Llandovery of the type area, and at the eastern end by the Rhavader Pale Shales, which represent a higher horizon of that stage. Dr. H. Lapworth showed (op. cit. p. 122, fig. 19) that uplift of the western end of the Rhayader district, followed by vigorous erosion, occurred before the deposition of the Caban Conglomerate. It is probable that the overstep of the Upper Llandovery over the Lower at the northern end of the Garth district may be attributed to elevation along the same axis which would therefore range in a north-westerly direction. another locality may be added to those of Llandovery and Garth, where, owing to differential movements along transverse axes, the Middle Llandovery rocks are confined to a limited area.

It may be remarked here that, whereas the unconformity at the base of the Upper Llandovery is as well-marked in the graptolitic facies of the Rhayader district as it is in the shelly facies at Garth and Llandovery, the unconformity at the base of the Middle Llandovery Series, which is so pronounced in these districts, cannot be detected in the Rhayader area (see, however, H. Lapworth,

op. cit. p. 80).

The Upper Llandovery.

The Upper Llandovery rocks of Garth are much thinner than those of Llandovery, and it is impossible to establish a precise correlation between the subdivisions of the group in the two districts. The Garth development probably represents in an attenuated form the upper portion only (C_4-C_6) of the Upper Llandovery of the type-area.

At Llandovery the succession appears to be conformable from base to summit of that stage; but at Garth the uppermost division, namely, the 'Paste Rock' (Cd), oversteps at both ends of the district on to lower divisions, and at the northern end comes to rest

upon the Lower Llandovery.

Relation of the Wenlock Series to the Llandovery.

In the central region of the Garth district the upper division of the Llandovery Series (Cd) is similar lithologically to parts of the basal member of that group (Ca), and appears to rest conformably on the underlying division (Ce). Near Hafod-yr-ancre in the same region, mudstones of this type, containing *Monograptus crenulatus* and *M. priodon*, become gradually darker and mottled, and pass by insensible gradations into striped shaly mudstones of Wenlock age, containing in addition *Cyrtograptus murchisoni*. So gradual is the change that it is impossible to determine on lithological evidence the precise position at which the boundary

between the olive-green mudstones and the striped Wenlock shales should be drawn. The beds in which *C. murchisoni* first appears have been adopted as the basal beds of the Wenlock Series.

The evidence of this section, combined with the overstep of the olive-green mudstones on to lower horizons, appears to suggest that these mudstones (Cd) are allied to the Wenlock rather than to the Liandovery. On the other hand, as the Wenlock rocks are traced southwards, the basal beds change in character, and about three-quarters of a mile south of the last mentioned locality they become gritty, and rest upon soft greenish mudstones, which appear to be at a lower horizon than those upon which the Wenlock rests at Hafod-yr-ancre. This evidence goes to show that the Wenlock is either unconformable to, or has overlapped, the greenish mudstones, and at the southern end of the Garth district that formation transgresses on to the Bala Series.

Between this district and the northern end of the Llandovery district the relation of the Wenlock Series to the underlying strata has not yet been examined, but in the latter area the (Old Series) Geological Survey map represents the Wenlock as overstepping the Upper Llandovery. A cursory examination which one of us (O. T. J.) made appears to show that the map is, in that

respect, a correct representation of the geology.

Farther south, however, in the district south of Noeth Grûg and Cefn-y-gareg, greenish mudstones with thin micaceous bands, belonging to the uppermost part (C₆) of the Upper Llandovery, emerge rapidly from beneath the Wenlock deposits, and attain a considerable thickness. East of Llandovery this group is again overstepped, and only just enters the southern area of the Llandovery district. There is reason to believe that the zone of Cyrtograptus murchisoni has been overlapped, and the lowest beds of the Wenlock probably belong to the zone of Monograptus riccartonensis. From this point southwards to the neighbourhood of Gorllwyn-fawr the base of the Wenlock ranges nearly parallel to the strike of the Upper Llandovery; but at that place an exceedingly rapid overstep sets in once more, so that in the Sefin valley the base of the Wenlock has descended to within about 300 feet of the base of the Upper Llandovery.

These relations of the Wenlock to the Llandovery Series can only be explained by differential movements of the Llandovery rocks, followed by erosion, prior to the deposition of the Wenlock sediments. As in the Llandovery Epoch, the movements have occurred along axes lying transversely to the present line of strike, but they do not appear to coincide in position with the axes of earlier movements. The overlap from north to south in the Wenlock formation was the result of a general slope of the pre-Wenlock surface from the southern end of the Llandovery area towards the Builth area. Miss G. L. Elles demonstrated a similar overlap in the Wenlock of that area from north to south, and a still greater overlap from west to east against the Ordovician mass of the

Carneddau Hills.

Conclusion.

The faunal and lithological contrasts between the shelly facies of Llandovery and Garth and the graptolitic facies of the Rhayader district prove that, during the Llandovery Epoch, differential movements were in progress along lines trending roughly parallel to the present strike. These new investigations have shown that during the same period other movements occurred along axes lying transversely to that strike. The existence of two distinct sets of movements along axes lying nearly at right angles to one another is closely paralleled by the history of the South Wales coalfield during the Coal-Measure Epoch, and further studies on other areas and other formations may show that such movements have been of more frequent occurrence than has been hitherto supposed.

DISCUSSION ON THE THREE FOREGOING PAPERS.

Dr. T. T. GROOM said that he had listened with great pleasure to the Authors' accounts of the two areas described. It was very gratifying to have a detailed and luminous description of the Llandovery formation of Llandovery itself. The Authors had explained, in what appeared to be a very satisfactory manner, the peculiarities in the behaviour of the Llandovery rocks, and had thrown much light on the physical conditions of the times. He felt all the more inclined to accept the unconformities postulated, since two of them evidently occurred in the district lying immediately south-west of that described by Prof. Jones, a district with which the speaker had long been familiar. The Llandovery Beds on the River Sawdde, about 300 feet thick, appeared to represent a part of the Upper Llandovery of the type area. They were overlain unconformably by Wenlock Beds containing near the base Monograptus riccartonensis. They rested unconformably, not on older Llandovery Beds, as in the more northerly district, but on the Llandeilo Flags. It was to be hoped that the Society might look forward to further communications on the Llandovery district from the pen of Prof. Jones.

Prof. W. W. Watts drew attention to the significance of the occurrence of two unconformities in the Llandovery, and asked the Authors what bearing this occurrence would have upon their views as to the classification of the Valentian rocks. He hoped that it might be possible to save the name Tarannon, the

sequence of zones in which was now well understood.

Mr. S. W. WOOLDRIDGE said that he had made a few traverses across the Valentian rocks on both sides of the Towy Anticline, while working with Prof. L. D. Stamp on the Ordovician igneous rocks at Llanwrtyd. He had assumed that the conspicuous conglomerates, which succeeded the Bala mudstones west of Llanwrtyd and Abergwesyn, represented the base of the Llandovery Series in that region. In view of the fact that the Authors recorded conglomeratic bands in the Bala rocks of the area, he asked what, in their opinion, was the horizon of the Abergwesyn conglomerates.

The evidence presented of intraformational unconformity related to north-west and south-east axes of instability was of the greatest interest. Evidence of similar transverse folding was obtainable at Lianwrtyd. The north-east and south-west anticline, the core of which was occupied by the Ordovician igneous rocks, had an undulating axis, and pitched steeply at both ends. It seemed possible that the series of structural ripples thus indicated had controlled the drainage in some measure, for both the River Irfon and the Nant Cerdin brook crossed the main anticline inconsequently at right angles to its strike. Since Llanwrtyd lay roughly mid-way between the northern Llandovery district and Garth, these facts lent support to the Authors' suggestion that a transverse line of instability might be found in this area, forming one of the series of such folds described by them.

The results of contemporaneous movement at Llandovery and Garth seemed closely comparable with those described by Prof. A. H. Cox & Dr. A. E. Trueman in the Lias, which seems to have been affected by a radiating series of anticlinal axes, many of which continued to move during the deposition of the Oolites. Again, in the London Basin there was abundant evidence of contemporaneous movements, both along the strike and at right-angles thereto, which have a close relation to the varying thickness and lithology of the Lower London Tertiaries. It would thus appear that facts from widely-separated regions and horizons were so shaping themselves as to lead to a valuable generalization.

Mr. H. G. SMITH said that, as a result of his examination of the area north-east of that described by Mr. Andrew, he found himself in cordial agreement with the Authors in regard to the existence of north-west and south-east axes of folding. He was pleased to hear that Prof. Jones had found examples illustrating Mr. Lamplugh's principle of diminution of thickness with depth; this was a welcome

support for views that he had already formed.

The President (Dr. J. W. Evans) referred to Prof. Jones's remark that the Llandovery sediments were derived from land on the south-east. This would now lie beneath the great tract of Old Red Sandstone which extended in that direction. There must be in that area an unconformity still greater than those described in the paper, for the Old Red Sandstone, with (it might be) the Downtonian at its base, would overlie rocks at least as old as the Bala, and possibly of still greater antiquity.

Prof. O. T. JONES returned thanks to those present on behalf of Mr. Andrew and himself for their kind reception of the papers, and to various speakers for contributing additional information bearing

upon the problems discussed therein.

It was very helpful to learn from Dr. Groom that the unconformity at the base of the Llandovery was much more marked in the Llangadock district than it is in any part of the Llandovery district. Since it appears that the Lower Llandovery is conformable on the Bala and is nearly overstepped at the boundary between the two districts, the lowest Llandovery near Llangadock is probably the basal part of the Upper Llandovery.

Dr. Groom had been able also to prove that the base of the Wenlock was in the zone of *M. riccartonensis*, thus confirming the suggestion made in the papers regarding the overlap within the Wenlock Series.

Prof. Jones could not see his way to accept Prof. Watts's suggestion to classify the Llandovery rocks into Lower Llandovery, Upper Llandovery, and Tarannon. The rocks now known as Middle Llandovery have never been included in the Upper Llandovery. The boundaries mapped by the Geological Survey officers for the Upper Llandovery practically coincide with those mapped by the Author. The term Tarannon was shown by Dame Ethel Shakespear to be equivalent to the Gala of the South of Scotland, and to be conformable with the Upper Birkhill. It now appears that the true physical base of the Gala or Tarannon Series is the base of the Upper Birkhill: namely, the zone of Monograptus sedgwicki, and not the zone of Rastrites maximus. This necessitates some revision of the existing classification, since Lower Llandovery and Middle Llandovery can be equalized approximately with Lower and Middle Birkhill respectively; but the Upper Llandovery is equivalent to Upper Birkhill and Gala (or Tarannon). It will probably be better, for the present, to retain two classifications for the Valentian Series-one for the shelly facies, and another for the graptolitic facies.

Mr. Wooldridge's suggestion that the Llanwrtyd Wells area furnished evidence of a transverse axis of folding, occurring as it does midway between the Garth and Llandovery districts, was particularly interesting, and it might be that the igneous rock at Baxter's Bank, east of Rhayader, indicated yet another axis, possibly the same as that which was responsible for the overlap of the Rhayader Pale Slates over the Gigrin Mudstones at the eastern

end of the Rhayader district.

It was impossible to apply the term Caledonian to any given direction of folding, since the axes of the post-Silurian (Caledonian) period of folding ranged from north-and-south in North Wales to east-and-west in South-West Wales.

With regard to the President's enquiry, a preliminary examination of the pebbles in the Llandovery rocks of the northern area appeared to indicate that they had been derived from a volcanic area (probably

pre-Cambrian) lying east of the present outcrop.

The speaker also referred to the exhibited specimen showing the firmly-welded junction of the Upper Llandovery and the Lower Llandovery at the southern end of the Garth district. The junction could be observed only with difficulty until the specimen was polished; and yet at Llandovery a thickness of at least 1500 feet of Lower and Middle Landovery (also possibly Upper Llandovery) intervenes between the two horizons which are in contact in the specimen.

14. The Stratigraphy of the Laki Series (Lower Eogene) of parts of Sind and Baluchistan (India); with a Description of the Larger Foraminifera contained in those beds. By Winfred Laurence Falkiner Nuttall, D.F.C., M.A., F.G.S. (Read April 22nd, 1925.)

[PLATES XXIII-XXVII: FOSSILS.]

CONTENTS

CONTENTS.	
	Page
I. Introduction	417
II. Classification of the Laki Series	419
(b) Bolan Pass (Baluchistan).	
III. Description of the Geology near Meting (Sind) (a) Geological Mapping.	421
(b) Stratigraphical Geology of the Laki Series.	
(1) The Laki Limestone.	
(2) The Meting Shales.	
(3) The Meting Limestone	
(4) The Basal Laki Laterite.	
IV. The Age of the Laki Series, as Determined from the	
Foraminifera	428
	432
V. The Distribution of the Echinodermata	404
VI. Palæontological Details, including a Description of	
certain Foraminifera of the Laki Series	434
VII. Bibliography	449

I. Introduction.

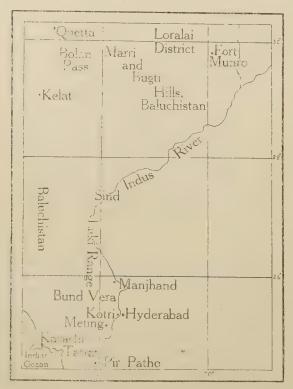
The following is a short account of the geology of the Lower Eocene Laki Series of the neighbourhood of Tatta, Meting, and the Laki Range in Sind, as well as of beds of the same age in the Bolan Pass (Baluchistan). The location of these places can be readily determined by reference to the map (fig. 1, p. 418). The first part of the paper includes a revision of the existing classification of the geological succession, and a brief description of the stratigraphy. In this respect the neighbourhood of Meting is of particular interest, as the highly fossiliferous lowermost beds of the Laki Series are well exposed, and so far in this area the true geological succession appears not to have been recognized.

The second part incorporates paleontological details, in particular with reference to foraminifera of the genera Alveolina, Nummulites, Assilina, etc. It is remarkable that several species with a limited stratigraphical range occur associated, just as they are in beds of similar age in Europe. The Indian representatives of these species have not been systematically examined or described since the classical Monograph on Nummulites by J. d'Archiac & E. J. A. Haime in 1853. At that time, specimens were not collected and separated according to their stratigraphical horizons,

nor is it clear often which of the figures refer to specimens from India.

The field work in the area was done during the winter of 1920–21 and in the latter part of 1923, when most of the fossils described were collected by Mr. D. Dale Condit and by myself. I wish to thank the directors of the Whitehall Petroleum Corporation for permitting the publication of information of scientific interest

Fig. 1.—Sketch-map showing the location of the area described, and the principal places mentioned, on the scale of 94.5 miles to the inch, or 1:6,000,000.



included in this paper. I also thank the Director of the Geological Survey of India and Dr. W. D. Lang, of the British Museum (Natural History), for the loan of specimens mentioned in the text. Prof. H. Douvillé has given me valuable advice, and presented me with specimens from France, which are mentioned later. Mr. A. G. Brighton has kindly named the echinodermata from the Meting Limestone. The types of the newly described species are placed in the Sedgwick Museum, Cambridge.

The numbers in parentheses after names in the text relate to bibliographical references at the end of the paper (§ VII, p. 449). Throughout the palaeontological portion the synonymy of the species is incomplete, the references given being those most useful for identification.

II. CLASSIFICATION OF THE LAKI SERIES.

The principal classifications and descriptions of the stratigraphy of the Laki Series of Sind and Baluchistan are those of W. T. Blanford (3 a), R. D. Oldham (44 & 45), and E. Vredenburg (59, 60, 61, 63), all at one time officers of the Indian Geological Survey.

(a) Sind.

In 1880 Blanford included in the Kirthar Series the massive limestone of the Laki Range and other outcrops of limestone containing Nummulites or Alveolinæ in Sind. F. Nætling (43) was the first to recognize that the massive limestones of Sind were older than those of the Kirthar Range, and proposed the term Laki for these beds. In 1909 Vredenburg $(61\,a)$ included in the Laki Series of Sind: - 'The Alveolina Limestone' and 'The Meting Shales,' which are underlain by the Upper Ranikot.

In his table of geological formations he described the Laki

Series as follows :-

'Alveolina Limestone, a massive white or pale-coloured rock, with locally at its base 30 to 50 feet of shaly limestones constituting the Meting Shales. The leading fossils are Nummulites atacicus and Assilina granulosa.

Approximate thickness of the whole group=500 to 800 feet.

Age: Lower Lutetian.

Owing to his not having understood the geological structure in the neighbourhood of Meting, Vredenburg's classification of the Laki Beds of Lower Sind is incomplete. In the present paper a geological map of the area near Meting is published, an account is given of the true geological succession, and the following divisions in the Laki Series are proposed :-

	1 1	Thickness in feet
(1)	The Laki Limestone	200 to 600
(2)	The Meting Shales	95
	The Meting Limestone	
(0)	The Basal Laki Laterite	25
(4)	The Basai Laki Labelito	

underlain by the Upper Ranikot.

Throughout Sind there are unconformities at the base and top of the Laki Series. The extent of the unconformity at the base is discussed later. At the top of the series along parts of the Laki Range the Laki Limestone is overlain unconformably by the Middle Kirthar, the Ghazij Beds and Lower Kirthar of Baluchistan being absent. In Lower Sind, near Tatta, the Meting Limestone is overlain by the Oligocene Nari Beds, the Laki Limestone being absent. Near Bund Vera the Laki Limestone is overlain unconformably by the Lower Manchar Beds (Pliocene).

(b) Bolan Pass (Baluchistan).

The Laki Beds of those parts of Baluchistan which include the Marri and Bugti Hills, as well as the Bolan Pass and country near Quetta, have been described and mapped by Griesbach (31), Blanford (4), Oldham (44a & 45a), and Pilgrim (50). The succession of rocks consists of the Dunghan Limestone overlain by the Ghazij Shales, which pass up conformably into the massive Lower Kirthar Limestone. The Dunghan Limestone may vary in thickness from several hundred feet to 50 feet or less. Where the Dunghan Limestone is thin it is conglomeratic, indicating an unconformable contact at the base of the Eocene. Its mode of origin has been discussed by Oldham, Blanford, and Vredenburg (60 a).

The section of the Laki Beds west of Bibi Nani, and near

Gokurth in the Bolan Pass, is as follows:-

DUNGHAN LIMESTONE, GHAZIJ SHALËS, (Thickness= 1500 feet.) Olive to grey fissile shales, with limestone-bands near the top, and some thin sandstone-beds in the lower third containing lignite and plant-impressions. The foraminifera from these beds include Nummulites atacicus, N. irregularis, Assilina granulosa, Alveolina ovicula sp. nov., Discocyclina archiaci var. baluchistanensis nov. Hard, dark-grey, massive limestone, which is usually conglomeratic. The conglomerate facies is well exposed in the Parri Nala, west (Thickness= of Bibi Nani, where the boulders range from 6 to over 12 inches in diameter, and are dull purplish-grey in colour. They are enclosed in a yellowish-grey, somewhat softer matrix. Both boulders and matrix are full of foraminifera of the same species. The fossils from this horizon include Nummulites atacicus, N. irregularis, Assilina granulosa, Alveolina lepidula, Alveolina subpyrenaica, Flosculina globosa, Orbitolites complanata, and Opertorbitolites douvilléi gen. et sp. nov.

In the Bolan Pass the Dunghan Limestone rests unconformably on massive limestone and shale, considered to be of Cretaceous age. At Fort Munro, about 150 miles east-north-east of the Bolan Pass, the Dunghan Limestone overlies the Cretaceous Pabb Sandstore

(62).

Flosculina globosa, which in Sind is restricted to the Meting Limestone, is common in the Dunghan Limestone. On the basis of the occurrence of this fossil and other species mentioned above, the Dunghan Limestone is correlated with the Meting Limestone of Sind. It is probable that the lower part of the Ghazij Shales is of deeper-water origin and equivalent in age to the Laki Limestone of Sind, the reason for the scarcity of Alveolinæ in the shaly facies of the Laki Series being mentioned on p. 428. The upper part of the Ghazij Shales is certainly younger than any beds of the Laki Series examined in Sind, as the Ghazij Shales pass up conformably into the Lower Kirthar. In Sind the Laki Limestone is overlain unconformably by the Middle Kirthar, there being a gap in the stratigraphical succession at this point.

Throughout the Kelat State, the Marri and Bugti Hills, and

the Loralai District of Baluchistan, the Dunghan Limestone is the lowest representative of the Tertiary, the Ranikot Beds of Sindbeing absent.

III. DESCRIPTION OF THE GEOLOGY NEAR METING (SIND).

(a) Geological Mapping.

The accompanying geological map (fig. 2, p. 422) illustrates the distribution of the formations that I have recognized in the area near Meting. It will be observed by an examination of this map that throughout the region the inclination of the strata rarely exceeds 2°, the area being one of gentle, approximately north-and-south folding, accompanied by strike-faults with an eastward upthrow. North of Meting is a gentle anticlinal fold, faulted on its eastern flank, and in the southern part of the map the beds dip uniformly westward at low angles. It is in this southern portion that the best section of the Laki Beds is exposed, and the rock-succession found here is represented graphically by the vertical

section (fig. 3, p. 423).

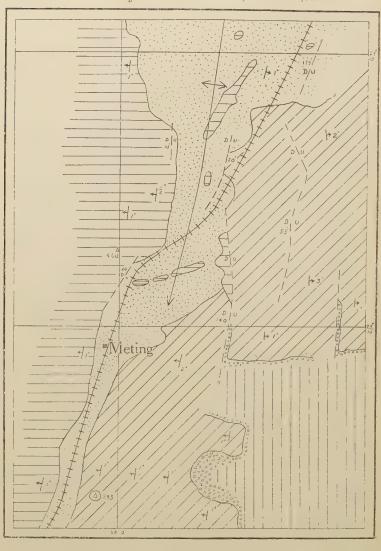
Before proceeding to a description of the stratigraphy I wish to point out how my geological mapping differs from that of Vredenburg (61). North-east of Meting he maps a tongue-shaped outcrop of what he calls 'Meting Shales' extending along the railway, east and west of which he has mapped 'Alveolina Limestone', which division of his is (as described above) stratigraphically higher than his 'Meting Shales'. It is evident that he has interpreted the structure here as an unbroken anticline with the same limestone-beds on each flank, and in the core a belt of Meting Shales. In regard to this I disagree with him, as the respective limestones on the two flanks of the anticline are of different age. That on the west I call the Laki Limestone and that on the east the Meting Limestone, the Meting Shales of my terminology being situated stratigraphically between these two limestones.

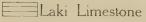
My view of the geological structure north of Meting is made clear by an examination of the geological map. The fault shown north-east of Meting has left as a topographical feature an eastward-facing scarp formed by the Laki Limestone, which along the line of dislocation dips westwards, thereby exhibiting 'drag'-phenomena due to the movement. There are also slickensided

surfaces along the line of fracture.

South and south-east of Meting Vredenburg mapped his 'Alveolina Limestone' underlain by 'Meting Shales,' which rest directly on the Upper Ranikot. Since he failed to recognize that the Laki Limestone and Meting Limestone are different, he included in his 'Meting Shales' both my Meting Shales and the Basal Laki Laterite. These two last-mentioned formations are in some places lithologically very similar; but they are easily distinguished south of Meting, and are separated by the Meting Limestone. It is evident, therefore, that it will be necessary to restrict the term Meting Shales to the beds intermediate between the Laki and

Fig. 2.—Geological map of the neighbourhood of Meting (Sind), on the scale of 2 miles to the inch, or 1:126,720.





Meting Shales

Meting Limestone

Basal Laki Laterite

Upper Ranikot

Formational boundary

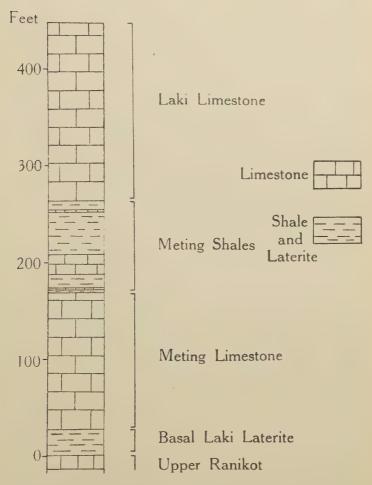
 $-\frac{u}{2}$ Fault with amount of displacement in feet.

Mr Dip and Strike

+-- North Western Railway

the Meting Limestones. It will be pointed out later that these two limestones can be recognized by their distinctive faunas.

Fig. 3.—Stratigraphical column showing the sequence of the Laki Series, south-west of Meting (Sind). Vertical scale: 100 feet=1 inch.



Vredenburg's term 'Alveolina Limestone' (adopted from Griesbach, 31), is unsuitable, as Alveolina are very abundant, both in the Laki and in the Meting Limestone. It is therefore proposed to cease from using the term 'Alveolina Limestone' as defining a stratigraphical unit.

(b) Stratigraphical Geology of the Laki Series.

Owing to the low angle of dip prevalent in the area near Meting no great thickness of strata is exposed, the total thickness of the beds measured being a little over 400 feet, as shown in the vertical section (fig. 3, p. 423). The rocks are divided as follows:—

	Thickness in feet,
	about 3 miles south of Meting.
The Laki Limestone	200
The Meting Shales	95
The Meting Limestone	140
The Basal Laki Laterite	

(1) The Laki Limestone.

Near Meting the Laki Limestone consists of about 200 feet of massive, creamy-white to buff limestone with hard members, which form a series of terraces and scarps north and west of Meting. The outliers of Laki Limestone near the axis of the anticline are flat-topped hills, rising 150 feet or so above the practically level ground occupied by the soft Meting Shales. The limestones are usually chalky in texture, and near Meting are noticeably less fossiliferous than the underlying Meting Limestone. I was unable, during a hasty reconnaissance in the area, to make a complete collection of fossils, but endeavoured to obtain samples of rock

containing foraminifera.

The Laki Limestone crops out along the greater part of the Laki Range, on the western flank of which it forms a prominent scarp extending for over 30 miles. Its thickness here varies from 600 to 800 feet, and it is usually hard, white, massive or nodular, and often almost entirely made up of Alveolinæ, as in Pl. XXIII, fig. 2. It is found on each side of the Bund Vera plain, and along the North-Western Railway for most of the way from Manjhand to a point about 10 miles south of Meting. It also forms some low hills on the east of the Indus River extending about 16 miles south of Hyderabad, and is observed in several hill-ranges of Thana Bula Khan Taluqa (Karachi District), as has been mentioned by Vredenburg.

The fauna consists mainly of:—Alveolina subpyrenaica (very abundant, often making up thick beds), Alveolina oblonga, Nummulites atacicus, N. mamilla (!), Assilina granulosa, Orbitolites complanata; casts of Natica, Crassatellites, Pectunculus, Nautilus, etc.; numerous echinodermata, which have been described by Duncan & Sladen (see p. 432), and of which more than twenty species have been recorded from localities where the Laki Limestone crops out, but are not recorded from areas

occupied by the Meting Limestone.

(2) The Meting Shales.

These beds consist of reddish-brown lateritic clay, gypseous shales, and soft, thinly-bedded, sandy limestones, all stained reddish

brown. Small forms of Assilina granulosa occur abundantly in some of the impure limestones. The Meting Shales represent a period, which was probably partly terrestrial and partly marine littoral, intermediate between the deposition of the marine Laki Limestone and that of the Meting Limestone. Where seen, the contact of the Meting Shales with the overlying Laki Limestone was sharp and unconformable. At the base of the Meting Shales there is no gradual transition downwards from the ferruginous shales to the nearly white Meting Limestone, the change being abrupt; and in the northern part of the area the top of the Meting Limestone shows definite evidence of erosion previous to the deposition of the Meting Shales, indicating a local unconformity.

The Meting Shales are well exposed near Trigonometrical Station 293 at the south-western corner of the map, and the section measured is shown in fig. 3 (p. 423). Starting from the base of the Laki Limestone, and extending downwards to the top of the Meting Limestone, the section of the Meting Shales is as follows:—

Clay, lateritic, dark red-brown, unfossiliferous Linestone, hard, sandy	in feet 10
Clay, brown, lateritic, gypseous, with some ferruginous sandstone-bands Limestone, sandy, ochreous Shale, sandy, ferruginous Limestone, very sandy, ferruginous, with many	45 19 15
small Assilina granulosa	2 3 — 95

The Meting Shales are well exposed near Meting, and, when traced southwards, become more difficult to recognize, as the beds are much covered by alluvium, and also, since their inclination becomes very low indeed, it is difficult to determine their thickness.

South of Tatta they are absent, as the Nari (Oligocene) Beds rest unconformably on the Meting Limestone. In the hills west of Kotri and Bund Vera the Laki Limestone rests unconformably on the Upper Ranikot, the Meting Shales and Meting Limestone being absent. This unconformity is marked by about 10 feet of very ferruginous laterite, which has been mentioned by Blanford (3 b), and is the local representative of the Basal Laki Laterite described below.

(3) The Meting Limestone.

As stated above, Vredenburg has confused this limestone with the Laki Limestone. It is a massive, nodular, creamy-white Alveolina limestone similar lithologically to the Laki Limestone, but primarily distinguished from the latter near Meting by its lower stratigraphical position, and secondly by being much more fossiliferous and containing a somewhat different fauna, as described below. An uninterrupted section of the Meting Limestone is

2 F 2

exposed east of Trigonometrical Station 293 in the southern part of the map (fig. 2, p. 422). Starting from the base of the Meting Shales and extending downwards to the top of the Basal Laki Laterite the succession is as follows:—

terite the succession is as Iollows:—	
Thickness	in feet
Limestone, creamy white, chalky, with a capping bed which	
is harder than the underlying rock, so as to form a local	
terrace. This limestone contains gasteropod casts, and	
Orbitolites complanata	23
Limestone, white, rubbly, the lower half containing a great abundance of Alveolina subpyrenaica, and some Flosculina globosa. This bed can easily be recognized throughout the area near Meting, as it is only at this horizon that	
the rock is almost entirely made up of the above fossils. (See Pl. XXIII, figs. I & 3)	21
Limestone, hard, nodular, creamy white, with Flosculina globosa and Alveolina oblonga. At the top is a terrace-forming member with many Orbitolites complanata and also Velates schmideli, as well as numerous pelecypod and gasteropod casts. Some 20 feet from the base, the following echinoderms are abundant: Rhynchopygus pygmæus Duncan & Sladen, Rh. cf. calderi D'Archiac & Haime, and Metalia soverbyi D'Archiac & Haime	96
Total thickness of Meting Limestone measured	140

The Meting Limestone occupies a wide area north-east and east of Meting, as shown in the accompanying map (fig. 2). From near Meting it can readily be traced southwards for about 40 miles, and near Tatta forms the Mukli Hills, which extend south to near Pir Patho. A section of the lower part of the group was examined where the main road from Tatta to Jungshahi cuts through the Mukli Hills, and is as follows:—

the contract of the contract o	
Thickness	in feet.
Limestone, hard, nodular, very light creamy-brown. Flos-	J
culina globosa is very abundant, forming most of the	
rock, and Alveolina subpyrenaica, as well as A, oblonga, is	
also found. This bed caps the hills on which the ancient	
tombs of the former kings of Sind are built	16
Shale, variegated, pale grey to purplish	4
Shale, weathering dark brown	13
Limestone, hard, yellow, rubbly, containing Flosculina	
globosa	6
Limestone, soft, marly, pale yellow, yielding Assilina	
granulosa and Nummulites atacicus	2
Limestone, slightly creamy-yellow, but on the whole re-	
markably white, compact, and nodular. Fossils very	
abundant, including Assilina granulosa, Nummulites	
atacicus, a few Flosculina globosa, also Ostrea, Velates	
schmideli Chemnitz, Nerita affinis D'Archiae & Haime,	
and echinoderms	5
Total thickness of section measured	46
- The three of section measured	-40

Near Trigonometrical Station 191 on the Mukli Hills, about 7 miles south-east of Tatta, there is a thickness of about 140 feet

of white to creamy-yellow nodular Meting Limestone, containing Alveolina subpyrenaica and Flosculina globosa. Near the base are highly fossiliferous beds yielding Assilina granulosa, Nummulites atacicus, Nautilus sp., Nerita affinis, Eolampas excen-

trica Duncan & Sladen, and various pelecypod casts.

The Meting Limestone is absent west of Kotri, and near Bund Vera, where it probably was never deposited (for reasons which are discussed below). East and south-east of Meting the Meting Limestone rests unconformably on the Ranikot, with the Basal Laki Laterite intervening. In this area it is easy to distinguish the Upper Ranikot from the Meting Limestone by their lithology alone. The Upper Ranikot limestones are somewhat arenaceous, ferruginous, and brown in colour, whereas the Meting Limestone is nearly pure calcareous and white to creamy yellow. The faunas of the two formations are distinct, and, as regards foraminifera, the only species that I have found common to the two are Flosculina globosa and Alveolina oblonga. These species, which are abundant in the Meting Limestone, are relatively uncommon in the Upper Ranikot, where they occur as dwarfed forms.

With the exception of Flosculina globosa, which is extremely abundant in the Meting Limestone, and has not been found in beds above this horizon, the foraminiferal fauna of the Laki and Meting Limestones is, so far as I know, identical. The Meting Limestone is the more fossiliferous of the two, and contains numerous echinoderms, certain species of which have not been recorded from the Laki Limestone (see p. 433). It is evident, however, that the stratigraphical break between the Meting and the Laki Limestones, represented by terrestrial conditions during part of the deposition of the Meting Shales, is small, as there is on the whole little change in fauna. On the other hand, the fauna of the Upper Ranikot is markedly different from that of the Meting Limestone, and the stratigraphical break here was one of

much greater duration.

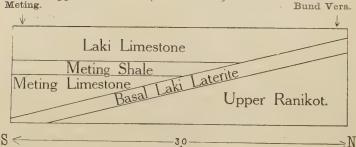
(4) The Basal Laki Laterite.

East of Meting this bed consists of about 25 feet of lateritic clay, which is highly ferruginous, with concretions of iron oxide and interbedded sandy layers. It represents a land period accompanied by erosion, between the marine deposition of the Upper Ranikot and that of the Laki Series. Near Bund Vera and west of Kotri the Laki Limestone rests on this laterite. Near Meting, as well as farther south, the Meting Shales and Limestone intervene. It would appear from this that, during the deposition of the Laki Series in Sind, the sea transgressed northwards, and while the Meting Limestone was being deposited near Meting, the neighbourhood of Bund Vera was land. The distribution of the beds in this area is made clear by the diagrammatic cross-section, fig. 4 (p. 428), extending from Meting to Bund Vera, and illustrating the unconformity at the base of the Laki Series, with northward overlap.

South of Tatta is a narrow belt of Basal Meting Laterite at the eastern foot of the Mukli Hill-scarp. In part of this area the laterite is intercalated with thin impure limestones containing Assilina granulosa, and the stratigraphical break at this point with the underlying Upper Ranikot is less than that seen elsewhere in Sind. North of Bund Vera the hiatus increases steadily, and in the Laki Range the Basal Laki Laterite, overlain by the Laki Limestone, rests upon the Lower Ranikot, as has been described by Blanford and others.

It is interesting that Alveolinæ, which are so abundant in the Laki, Meting, and Dunghan Limestones, are not found in the impure limestones of the Meting Shales, nor in similar beds of the Basal Laki Laterite south of Tatta, and are rare in the

Fig. 4.—Diagrammatic cross-section from Bund Vera to Meting, showing the unconformity and overlap of the Laki Series on the Upper Ranikot. (Not to scale.)



Ghazij Shales of Baluchistan. It is evident that Alveolinæ throve only in a clear sea, and in this respect it is interesting to note that the existing species $Alveolina\ melo$, according to Brady (6), is not found in water at a greater depth than 40 fathoms. $Assilina\ granulosa$, on the other hand, is everywhere abundant in the shaly facies, and on the whole uncommon in the pure limestones.

miles

IV. THE AGE OF THE LAKI SERIES, AS DETERMINED FROM THE FORAMINIFERA.

Previous Classification.

In 1906 Vredenburg (60 c) classified the Laki Series as Lower Lutetian, and in 1921 made the following statement as to their age (63, pp. 325-26):—

'A study of Indian Tertiary geology undoubtedly reveals the presence of a vastly developed intercalary stage, the Laki, intervening between the equivalents of the Cuisian and Lutetian and corresponding with neither. It is equivalent to the Lybian Stage of Egypt. In the Paris Basin it corresponds to a stratigraphical gap between the Cuisian and Lutetian, first recognized by Lemoine, who has given the name of Laonnian to the scanty fresh-water or brackish representative of the missing zone, occasionally occurring as discontinuous patches (1911, "Géologie du Bassin de Paris" p. 220).'

In the passage cited Prof. Paul Lemoine never asserted that the Laonnian represented a stratigraphical gap in the Lower Eocene, his definition of this term being as follows:—

'La partie supérieure de l'Yprésien est souvent d'origine lacustre ou fluviatile, , il serait logique de donner un nom, par exemple, Laonnien aux faciès lagunaires du sommet de l'Yprésien.'

There is no evidence of a stratigraphical gap at this horizon in

the Paris Basin, nor is this view generally accepted.

When comparing the Eocene fauna of India with that of Europe it is important to bear in mind, that, so far as we know, in Lower and Middle Eocene times a vast southern ocean extended from Southern France eastwards to Italy, Northern Africa, Persia, and Western India. It would, therefore, be expected that in these areas the same species of foraminifera would probably occur at approximately the same stratigraphical horizons. On the other hand, it is safer not to make detailed comparisons of the stratigraphy and fauna of the Anglo-Gallic Basin with that of India, as the former was at intervals cut off from the Southern Ocean.

Also, in determining the age of Eocene rocks in these widely-separated areas, an important factor to be remembered in correlation is the rate of migration of the species of foraminifera. In this regard, although little is known, it would be reasonable to suppose that the minute tests of the young forms could be carried for considerable distances by currents, and, since they existed in large numbers, their distribution would probably be rapid.

Species of Foraminifera common to India and to Europe.

The following foraminifera, which are found in the Laki Series, also occur in Europe:—(only the microspheric form is quoted) Nummulites atacicus, N. irregularis, Assilina granulosa, Alveolina oblonga, A. subpyrenaica, Flosculina globosa, and Orbitolites

complanata.

In Southern France the stratigraphical sequence and the zonal distribution of the foraminifera of the Lower Eogene formations have been worked out in more detail than elsewhere in Europe, and this area is therefore of the greatest value for comparing the Laki Beds of India with the Lower Eogene of Europe. Also, in Southern France the formations contain described molluscan and echinoderm faunas, as well as the above-mentioned species of foraminifera, and their age has been determined with considerable accuracy. In Italy the Lower Eogene is generally not so fossiliferous, nor is the fauna so well known as that in Southern France.

Doncieux, in giving an account of the Nummulitic beds of the Montagne Noire and the Minervois (18 a) finds the following foraminifera:—Nummulites atacicus, Assilina granulosa, Operculina granulosa, O. ammonea, Alveolina subpyrenaica, A. oblonga, Flosculina globosu, and Orbitolites complanata. He considered these beds as of Lower Lutetian age, but more recently Prof. H. Douvillé has shown them to be Lower Eocene (22 a).

The strong resemblance of this faunal assemblage to that of the Laki Series is remarkable; of the eight species that occur, six are found in the Laki Series.

In 1919 Douvillé, describing the Lower Eocene of Aquitaine and the Pyrenees (22b), finds associated with Assilina granulosa the following nummulites: -Nummulites globulus, N. atacicus, N. planulatus, N. murchisoni, N. irregularis, N. lucasi, N. pustulosus, N. granifer, N. aquitanieus, and N. exilis. In 1922 the same writer (24) summarized our knowledge of the Lower Eocene south of the Pyrenees. Beds equivalent to the Thanetian in the Corbières of Southern France contain Nummulites atacicus, N. globulus. Alveolina subpyrenaica, Flosculina globosa, and Orbitolites complanata. The beds equivalent to the Cuisian of Bos Arros contain Nummulites atacicus, N. lucasi, N. planulatus, N. aquitanicus, N. granifer, N. globulus, N. irregularis, and Assilina granulosa. In 1924 Douvillé (25) described the foraminiferal fauna of Béarn and found the following foraminifera in beds of Cuisian age: Nummulites atacicus, N. murchisoni, N. granifer, N. parvus, N. parvulus, N. mamillanus, N. planulatus, and Assilina granulosa.

Of the species mentioned above as occurring in India, in Southern France, according to Douville's latest views, the stratigraphical range of Assilina granulosa is restricted to the Lower Eocene (22 c). Nummulites atacicus in France and Italy ranges through the Lower Eccene and Lutetian (22 a, 5 a, 5 c, 27, 28). Y. irregularis is found in the Ypresian and Lower Lutetian of Southern France (22 h, 5 c), and in the Lutetian of Italy (27, 28). Alveolina oblongu is common in the Ypresian of Gan (22), Aquitaine (22 k), the Corbières, and the Montagne Noire (18 a), Cuise (36), etc.; it has also been recorded from the Lutetian of Italy (28, 14). Alreolina subpyrenaica and Flosculina globosa are characteristic Lower Eocene fossils, forming limestonebands in the Corbières and Montagne Noire areas (18 a). Orbitolites complanata is common in the Lutetian of the Paris Basin (21 d), also in the Ypresian of the Corbières, the Montagne Noire (18 a), and south of the Pyrenees (24). In Italy it is recorded from the Lutetian (27, 28). Numerous other occurrences of these species might be mentioned, but those enumerated above are sufficient to show their stratigraphical range.

The knowledge of the stratigraphical distribution of the foraminifera in the Eocene of Italy, Egypt, Persia, and other regions in Europe and Asia, is not yet sufficient to make detailed comparisons of the fauna of those areas with that of the Laki Series of Sind. It is probable that the upper part of the Lybian in Egypt, containing abundant Alveolina, as described by Zittel (64), is of the same age as the Laki Series of Sind. In Tibet Orbitolites complanata is found in Eocene deposits, together with Alveolina oblonga

(21 d).

In Southern France (221), Italy, the Alps, and Northern Africa (27) the Lower Lutetian is characterized by the appearance of

Numnulites lævigatus and not infrequently by the presence of N. obtusus (=perforatus, =aturicus auctorum). These species in India occur in the Kirthar Series, and are not found in the Laki Series.

A common and very typical European Ypresian nummulite is Nummulites planulatus, which in India occurs in the upper part of the Upper Ranikot, and has not been found in the Laki Series. Although the Laki Series contains several species of foraminifera characteristic of the Ypresian, Nummulites planulatus is only found in the Ranikot Series. It would seem that this species made its appearance somewhat earlier in India than in Europe, and became extinct in the former country at a period when other species typical of the European Ypresian survived.

The Mollusca.

The mollusca of the Laki Series have not so far been systematically studied. Among the commoner gasteropods is *Velates schmideli*, a form characteristic of the Ypresian of the Paris Basin and parts of Southern France; it also occurs, however, in the Lutetian of Europe. The gasteropods of the underlying Upper Ranikot Series have been studied by Cossmann & Pissarro (15), who have classified the beds as Ypresian. These authors have described over 100 species, which according to them are all different from European forms. It is clear from this that the mollusca are of less value in comparing the Lower Tertiary faunas of Europe and India than the larger foraminifera, which existed in such enormous numbers and had so wide a distribution that they may be considered of great value in this respect.

Conclusion.

Although, so far as we know, the Indian fauna of foraminifera is not so rich in species as that of Southern France, it is remarkable that there should be the same assemblage of species, which in Southern France are found associated in beds of Lower Eocene age (Thanetian and Ypresian). Nummulites lævigatus and N. obtusus, which in Europe occur in the Lower Lutetian, are not found in the Laki Series, but occur higher up in the Kirthar Series.

In conclusion, the evidence from the foraminifera is in favour of considering the Laki Series of India as of Lower Eocene age

1 Velates schmideli (Chemnitz). This species occurs in the Meting Limestone near Meting, and Noetling (42) has figured it from the Laki Limestone of Kharguzani Hill in the Laki Range. I possess good specimens of this fossil, which I have compared with V. schmideli from the Eocene of the Paris Basin, and can discern no difference between the two. It is easy to separate this species from the related Indian forms. I have collected specimens of V. nætlingi Cossmann & Pissarro (15) from the Upper Ranikot near Trigonometrical Station 685, Bund Vera (Sind). V. nætlingi and V. tibeticus Douvillé (21b) from the Danian of Tibet are both more elongate and depressed, as well as having the umbo well below the apex.

rather than Lower Lutetian, as has been supposed hitherto. The results of my study of the foraminifera of the Ranikot and Kirthar Series, which will be published shortly, will throw further light on this subject.

The following table summarizes the stratigraphical distribution of the foraminifera of the Laki Series, based on occurrences in parts of Sind and Baluchistan, mentioned in the palæontological portion of this paper. It will be observed that the stratigraphical range of the majority of the species is restricted to the Laki Series. Throughout Sind and Baluchistan the massive limestones of the Laki and Kirthar Series are indistinguishable by their lithology alone, so that the foraminifera are of value in determining their age.

Genus and species.	Upper Ranikot.	Meting and Dunghan Limestone.	Laki Limestone.	Ghazij Shales.	Lower Kirthar.
Nummulites atacicus Leymerie Nummulites mamilla Fichtel & Moll? Nummulites irregularis Deshayes Assilina granulosa E. J. A. d'Archiac Assilina exponens Sowerby Alveolina oblonga A. d'Orbigny Alveolina ovicula sp. nov. Alveolina lepidula Schwager Alveolina subpyrenaica Leymerie Flosculina globosa Leymerie Discocyclina archiaci Schlumberger, var. baluchistanensis nov. Orbitolites complanata Lamarck Opertorbitolites douvilléi gen. et sp. nov.					

V. THE DISTRIBUTION OF THE ECHINODERMATA.

As stated above, the Tertiary echinoids of Western India have been described by Duncan & Sladen (26). These authors mixed the specimens from the Laki and Kirthar Series; but, fortunately, the exact localities where they were collected are nearly always stated, and, by knowing the distribution of the Laki and Kirthar beds in these localities, Vredenburg (60b) has separated the species from the two series. I have taken the echinoids enumerated by Vredenburg as occurring in the Laki Series, and, by looking up the localities, have endeavoured to determine their distribution in the Laki and Meting Limestones. The results are tabulated below,

and it will be observed that, in the present state of our knowledge, the Laki Limestone contains many species which are not recorded from the Meting Limestone. Since for each species there are usually numerous localities quoted by Duncan & Sladen, this distribution cannot well be accidental, due to lack of collections from the area occupied by the Meting Limestone. Where I have been able to confirm an observation as to the distribution of any species from the Meting Limestone I have placed a capital N.

Genus and species.	Laki Limestone.	Meting Limestone.
Leiocidaris canaliculata D. & S		
Porocidaris anomala D. & S.		
Cyphosoma macrostoma D. & S		
Micropsis venustula D. & S.		
Arachniopleurus reticulatus D. & S		
Conoclypeus alveolatus D. & S.		
Echinocyamus nummuliticus D. & S		
do. do. var. obesus		
do. do. var. oviformis		
do. do. var. planus		
do. rotundus D. & S		
Amblypygus subrotundus D. & S		
Eolampas excentrica D. & S.		N.
Echinolampas rotunda D. & S		
do. subconica D. & S		
do. obesa D. & S.		
do. nummulitica D. & S		
do. lepadiformis D. & S		
Rhynchopygus calderi D'Archiac & Haime 1		N.
do. pygmæus D. & S. ¹		N.
Hemiaster apicalis D. & S		
do. nobilis D. & S.		
do. carinatus D. & S.	. ———	
do. digonus D'Archiae		
Brissopsis sufflatus D. & S.		
Metalia sowerbyi D'Archiac		N.
do. scutiformis D'Archiae		
do. do. var. rotunda D. & S		
do. depressa D. & S	· ———	
do. agariciformis D. & S		
Schizaster symmetricus D. & S		
Prenaster oviformis D. & S		
Macropneustes speciosus D. & S		
do. rotundus D. & S	SAVPIRE	
Euspatangus avellana D'Archiae & Haime		

¹ According to Vredenburg, these two species are probably identical.

VI. Palæontological Details, including a Description of Certain Foraminifera of the Laki Series.

Genus ALVEOLINA Defrance.

ALVEOLINA SUBPYRENAICA Leymerie. (Pl. XXIII, figs. 1-3 & Pl. XXIV, fig. 3.)

1826. Alveolina ovoidea A. d'Orbigny (46 a). 1844. Alveolina subpyrenaica Leymerie (40 a). 1905. Alveolina subpyrenaica Doncieux (18 b).

The Indian representatives of this species have an average length of 3.6 mm, and width of 2.3 mm, as obtained from measurements of fifteen typical specimens tabulated below. The average ratio of length to width is 1.6 to 1. The forms are all megalospheric, the average diameter of the primordial chamber being 270 μ . There are nine to eleven whorls, and in the last whorl the number of cells varies from 12 to 17 per mm. The following are external measurements in millimetres of the test of fifteen specimens from the Meting Limestone near Meting (Sind):—

Length.	Width.	Length.	Width.
5.6	3.4	3.5	2.5
4.1	3.2	3.3	1.9
4.1	2.6	3.2	2.4
4.1	2.2	3.2	2.0
4.0	2.6	3.1	2.0
4.0	2.6	3.0	1.8
3.8	3.0	2.7	2.0
3.8	1.9		

It will be observed by an examination of the figures showing cross-sections of the specimens that the thickness of the lamina between successive whorls of cells is variable. This is characteristic of the species; it has been mentioned by Doncieux (18 b), and is discussed below under the closely related species Flosculina globosa. Unfortunately, there are no figures published showing the internal structure of this species from the type-locality of the Montagne Noire in Southern France. Prof. H. Douvillé has kindly given me specimens from Barroubio (see Doncieux, 18 c), and it is by examining these that I have been able to place the Indian forms in the same species, Pl. XXIV, fig. 3 represents the longitudinal section obtained of a typical A. subpyrenaica, from the type-locality.

The Italian writers Osimo (48) and Checchia-Rispoli (14) have adopted for this species, which is found in Italy, the name A. sphærica Fortis, var. granum millii or milium, translated from the French 'Alvéolite grain de millet, Bosc. 1800'. This name is not in accordance with the accepted rules of binomial nomenclature. The species is, according to Douvillé (21a), synonymous with A. ovoidea, which was only mentioned, but never figured, by

A. d'Orbigny.

Occurrence.—This species is very abundant, both in the Meting and in the Laki Limestones, and not uncommonly constitutes nearly the entire rock:

- (a) From all outcrops of the Meting Limestone near Meting, and the Mukli Hills near Tatta (Sind).
- (b) From the Laki Limestone on the west side of Bund Vera Plain, near Murid (Sind).
- (c) From the Laki Limestone 5 miles south-east of Bund Vera. Indian Geological Survey, G 280/86.
- (d) From the Laki Limestone of the hills in the neighbourhood of Hyderabad (Sind). British Museum (Natural History) No. P 570.
- (e) From the Dunghan Limestone, Parri Nala, west of Bibi Nani, Bolan · Pass (Baluchistan).
- (f) From the Dunghan Limestone at Fort Munro, on the Dera Ghazi Khan-Baluchistan border.

Subgenus Flosculina Stache.

FLOSCULINA GLOBOSA Leymerie. (Pl. XXIII, figs. 1, 4, & Pl. XXIV, figs. 4–6.)

1844. Alveolina subpyrenaica var. globosa Leymerie (40 b).

1853. Alveolina spheroidea Lamarck, Carter (9 a).

1895. Alveotria spherottea Banarca, Carte (84). 1905. Flosculina globosa Leymerie, Doncieux (18 d). 1909. Alveolina bulloides A. d'Orbigny, Osimo (48 b). 1915. Flosculina pasticillata Schwager, Dainelli (16). 1916. Flosculina globosa Leymerie, Checchia-Rispoli (13 a).

Description.—The representative of this species from the Laki Series of Western India is subspheroidal to very globose ovoid. The average factor for the length divided by the width is 1.2. The size is variable, the average length being about 5 mm. and the average width 4 mm., as obtained from measurements tabulated on p. 436. Externally, the test is divided into twelve to fifteen longitudinal segments, separated by well-marked furrows.

Internally, the primordial chamber, which in all specimens examined is probably that of megalospheric individuals, is subcircular to elliptical in cross-section, the diameter varying from 170 to 240 μ. In a single specimen (Pl. XXIV, fig. 5) the primordial chamber was observed to be double, with an intermediate simple septum extending for the greater part of the distance across the chamber. The internal structure of the test shows a distinctive development during different periods of growth. This development is constant in specimens from the Meting Limestone of Lower Sind, and does not show the variations found in those from the type-locality of Southern France (see Doncieux, 18 d). The method of growth that is universal among the Lower Sind forms is as follows:—the primordial chamber is surrounded by three or four whorls which are very close together; there are then usually three whorls where the cells are widely separated; near the periphery are four to six whorls in close proximity.

In longitudinal cross-section of the test the cells are seen to be subcircular in shape near the periphery, and near the centre usually somewhat elongate, with their longer axis parallel to the radius. In the last whorl there are from thirteen to fifteen cells per mm. The following table gives the external dimensions (in millimetres) of specimens from the Meting Limestone near Meting.

Forty specimens arranged according to length.

Length.	Width.		Length.	Width
3.3	2.9		4.9	4.1
3.6	3.1		5.0	4.0
4.0	3.4		5.0	4.5
4.0	3.7		5.1	4.7
4.1	3.3		5.1	4.8
4.1	3.6		5.2	4.1
4.1	3.8		5.2	5.0
4.2	3.5		5.5	5.0
4.3	3.5		5.7	4.9
4.3	3.7		5.7	5.1
4.3	3.8		5.7	5.4
4.5	3.8		5.8	5.2
4.5	4.1		5.9	5.1
4.6	3.9		5.9	5.6
4.7	$4\cdot 2$		6.0	5.0
4.7	4.4		6.1	5.2
4.8	3.7		6.2	4.9
4.8	3.5	i	6.4	5.8
4.8	3.4		6.4	 6.1
4.9	3.4		6.6	6.3

Average length = 5.0 mm. Average width = 4.3 mm.

Previous mention and a related form in India.—The first mention of this very nearly spheroidal Flosculine in India appears to be by Carter in 1849 (8), who remarked on its abundance near Tatta. His figures illustrate roughly the internal structure, but no specific name was assigned to the fossil. A short description of the same form was given by Carter in 1853 (9a), under Alveolina spheroidea Lamarck, and his figure shows a diagrammatic view of the exterior.

In 1854 (10) Carter described and figured a spheroidal form of Alveolina under the name of Melonites spheroidea (Lamarck). The specimens were collected in the Bolan Pass between the towns of Dadur and Quetta, probably from the Dunghan Limestone. I have found no forms identical with his figured type; it is, however, related to the species now described, which occurs in the Bolan Pass. Carter's species does not belong to A. spheroidea Lamarck, which, according to A. d'Orbigny (47), Parker & Jones (49), Brady (6), and others, is synonymous with A. melo Fichtel & Moll. A. melo, according to Brady, is a very small form still living, and his figure of a recent specimen shows that its internal structure is that of a typical Alveolina. Carter's specimen has the structure of the subgenus Flosculina of Stache (55 a), showing a marked thickening of the wall between the cell-whorls, and is also larger than the typical Alveolina melo.

Blanford (3 c) and Fedden (29) have mentioned the occurrence of spheroidal Alveolinæ in Sind, and have referred them to the

species Alveolina spheroidea Lamarck. D'Archiae & Haime (2a) have referred Sind spheroidal Alveolina to A. melo A. d'Orbigny

and A. spheroidea (Carter).

Osimo (48) has also recognized that A. spheroidea Lamarck, Carter 1854 is different from Lamarck's A. spheroidea. She classified Carter's form from the lower part of the Eocene as a variety of A. bulloides A. d'Orbigny (which occurs in the Miocene of the Vienna Basin), and called it A. bulloides D'Orbigny, var. spheroidea Carter. This classification is unsatisfactory, as, in the present state of our knowledge, there are no described related forms from the stratigraphically intermediate strata, so that it is best to consider Carter's form as a separate species—Flosculina spheroidea (Carter, non Lamarck).

Carter's species does not exhibit peripheral whorls in close proximity, nor the divergence of the whorls in the central part of the test, as in *Flosculina globosa*. In his transverse section it is remarkable that the secondary septa form triangular orifices at all stages of growth in the test. It has been recently shown by Altpeter (1) that in one single individual a variable development of this septum may be present, depending on the periodic activity of the protoplasm. In view of this, the nature of the secondary septa cannot be relied upon as a specific characteristic. In the specimens of *F. globosa* from Sind I have not found this septum recurved.

A small form of *F. globosa* occurs in the Upper Ranikot of Lower Sind, with a diameter of 2 to 2.5 mm., and possessing about three whorls in close proximity near the primordial chamber and three

whorls well spaced in the outer part of the test.

Comparison of representatives of the species and related forms from Europe, Egypt, and Persia.—When Leymerie described the type of the species from the Montagne Noire he made no study of the internal structure. This has, however, been investigated by Doncieux (18 d), though it is unfortunate that no figures have been published illustrating this structure and its variations, as observed in specimens from the type-locality. Prof. H. Douvillé has kindly presented me with some specimens from the Montagne Noire, and it is evident, from an examination of a cross-section of these, that the amount of 'flosculination' (to use Schwager's term) is very variable.

Some forms from the Montagne Noire are identical with those that have been figured from Italy by Osimo (48) and Dainelli (16). Others present decreasing gradations of flosculination until typical Alveolina subpyrenaica (see Pl. XXIV, fig. 3) is reached, and some are indistinguishable from the form characteristic of Sind

described above. As Doncieux states,

Among the French specimens there appears to be no sharp line

^{&#}x27;On recontre de très nombreux spécimens (plus nombreux que la forme type) chez qui la lame spirale n'est pas épaisse partout, mais seulement sur l'espace de deux à quatre tours dans la partie moyenne.'

distinguishing Flosculina globosa from Alveolina subpyrenaica, and here we have apparently a transition from one genus to another. It would appear that flosculination is probably not a characteristic suitable for generic distinction, but may be only due to such conditions as the amount of calcium carbonate present in the water at the time. With an excess of carbonate in solution it would be reasonable to suppose that the organism's power of secretion of this mineral would be greater than under more normal conditions.

It is, however, convenient to retain the names of these two associated species. In Sind Flosculina globosa is only found in the Upper Ranikot and in the Meting Limestone, while A. subpyrenaica occurs in the Meting Limestone as well as in the Laki Limestone, which overlies it stratigraphically. Intermediate transitional forms are very uncommon. I have, however, examined specimens in the British Museum (Natural History) from farther north in India, in the Tochi River District, which exhibit characteristics intermediate between the two species.

With regard to the synonymy of the species, Osimo (48) has figured specimens of typical F. globosa from the Eocene of Italy, and has referred them to a Miocene species—Alveolina bulloides A. d'Orbigny. The internal structure of A. bulloides has not been described, but externally (Fornasini, 30) it possesses highly convex exterior sectors and a prominent last sector, in which respects it

bears no resemblance to F. qlobosa.

In 1913 Checchia-Rispoli (12) suggested a revision of Osimo's classification, and placed the specimens figured in the latter author's pl. vi (3) figs. 13–16 in the species F. pasticillata Schwager. Checchia-Rispoli suggested that the remaining specimen (fig. 18b) of Osimo's A. bulloides may belong to the subgenus Flosculinella of Schubert (54). In Alveolina Douvillé (=Flosculinella Schubert) the last whorls have more than one row of chambers, the superimposed secondary chambers being in some cases smaller than the larger ones near the interior (19, 20, 52). This is not the case in Osimo's fig. 18b, where the peripheral whorls are merely closer together than in the median portion.

The specimen (fig. 18 b of Osimo) is an adult Flosculina globosa, similar to the forms from Sind. It differs, however, from them in not possessing closely-set whorls near the primordial chamber, and it also has eight peripheral whorls in close proximity, whereas I have only observed a maximum of six in Sind forms. Dainelli's figure of F. pasticillata Schwager (16) is a typical F. globosa,

with peripheral whorls in close proximity.

In 1916 Checchia-Rispoli (13b) referred F. pasticillata Schwager from Egypt to F. globosa Leymerie, on the basis of Doncieux's description of the internal structure. Schwager's figure shows a different internal structure from that typically found in F. globosa. The species is, however, closely related; but Schwager's drawings are insufficient to establish their synonymy, and it will be necessary to compare actual specimens.

I have examined specimens of Flosculina globosa in the Loftus Collection from Kirrind, Persia (38, 41). These Alveolinæ were referred to A. subpyrenaica, but show characteristics more typical of a small F. globosa, with usually about six whorls, similar to those of the Upper Ranikot of Sind. Mr. R. K. Richardson, of the Anglo-Persian Oil Company, has sent me a specimen of limestone from Khamir (Persia) which contains large numbers of Alveolina subpyrenaica and F. globosa.

Occurrence.—F. globosa is remarkable for its established wide distribution, and, where found, appears to be characteristic of rocks of Lower Eocene age. I have examined specimens from the following localities in Western India:—

- (a) From the Meting Limestone, in the neighbourhood of Meting and the Mukli Hills near Tatta, in both of which places it is very abundant, often forming a great part of the rock.
- (b) From the Dunghan Limestone of Parri Nala, Bolan Pass, west of Bibi Nani (Baluchistan).
- (c) From the Dunghan Limestone of Fort Munro (Baluchistan Frontier).
- (d) From the Tochi River District (North-West Frontier Province). British Museum (Natural History) specimens P 7907.
- (e) From the Upper Ranikot Series, west of Hilaia Trigonometrical Station, south of Jerruck (Sind).
- (f) From the Upper Ranikot Series, $5\frac{1}{2}$ miles south-east of Meting (Sind).

ALVEOLINA OVICULA sp. nov. (Pl. XXIV, figs. 9 & 10.)

The length of the specimens examined varied from 5·2 to 4·1 mm. and the width from 3·6 down to 2·7 mm., the average ratio of length to width being 1·5·1. The characteristic internal development is as follows:—Surrounding the megalosphere, which does not exceed 100 μ in diameter, are from four to five whorls in close proximity. The whorls then become separated, as is typical with the subgenus Flosculina, there being from two to three widely spaced whorls. Near the periphery the whorls, which number from eight to eleven, are in close proximity. In the last whorl there are usually sixteen cells per millimetre.

The species nearest related is *Flosculina globosa*, from which it may be readily distinguished by being much more elliptical in cross-section, by having a smaller primordial chamber, and by possessing more whorls in the same radius along the shorter axis. In a typical example of *A. ovicula* there were thirteen whorls in a radius of 2 mm., as compared with seven whorls in 2 mm. for *F. globosa*.

This species is rare, and I have only been able to examine six specimens from the Ghazij Shales, immediately above the Dunghan Limestone of Parri Nala, near Bibi Nani, Bolan Pass (Baluchistan).

ALVEOLINA LEPIDULA Schwager. (Pl. XXIV, figs. 1 & 2.) 1883. Alveolina lepidula Schwager (55 b).

These forms appear identical with the Egyptian species, as Q. J. G. S. No. 323.

figured and described by Schwager. The species is the only microspheric form that I have found in India. It possesses from eight to eleven whorls, with about nineteen cells per mm. in the last whorl. So far, it has been found only in the Dunghan Limestone of Parri Nala, near Bibi Nani, Bolan Pass (Baluchistan). The following are the external measurements (in millimetres) of five typical specimens:—

Length.	Width
2.6	1.8
2:5	1.6
2.0	1.5
1.5	1.1
1.4	1.0

ALVEOLINA OBLONGA A. d'Orbigny. (Pl. XXIV, figs. 7 & 8.)

1826. Alveolina oblonga A. d'Orbigny (46 b). 1916. Alveolina oblonga A. d'Orbigny, Douvillé (21 c).

This species, which has recently been described and figured by Prof. H. Douvillé from the Eocene of Tibet, is common in the Laki Series of Sind. The average length is 7 mm. and the average width 3 mm. There are from eleven to fifteen whorls, with thirteen to fifteen cells per mm. in the last whorl. The forms found were megalospheric, the average diameter of the primordial chamber being 350 to $400\,\mu$. The external dimensions (in millimetres) of twenty specimens from the Meting Limestone, near Meting, are as follows:—

Length.	Width.	Length.	Width.
9.4	4.3	6.5	2.8
8.8	3.5	6.3	2.7
8.6	3.7	6.3	2.5
8.4	3.8	6.0	2.6
8.0	3.4	6.0	2.6
7.5	3.5	5.9	2.7
7.4	2.8	5.6	3.0
7.2	2.9	5.5	2.7
7.0	4:3	4.9	3:5
6.8	2.6	4.8	3,3

In India the species is readily distinguished from A. sub-pyrenaica: (a) by its higher ratio of length to width, which averages 2.5:1 compared with 1.6:1 for A. subpyrenaica; (b) by not having a tendency to develop a thick lamina between successive whorls; and (c) by having a larger adult development, the average length being 7 mm. as compared with 3.6 mm. for A. subpyrenaica.

The first record of cylindrical Alveolinæ from the Laki deposits near Hyderabad (Sind) is by Carter in 1844 (7), when no generic or specific name is assigned to the specimen figured. Later, in 1853 (9b) and in 1861 (11), Carter incorrectly referred these forms from Sind to A. elliptica of Sowerby (57). A. elliptica is a large Alveoline with a distinctive internal structure, a description of which I hope to publish shortly. It is restricted to the Kirthar

Beds, which are higher stratigraphically, and was originally described from Cutch. The specimens described by Carter are either Alveolina oblonga or A. subpyrenaica.

Occurrence.

- (a) Common in the Meting Limestone in the neighbourhood of Meting and the Mukli Hills, near Tatta (Sind).
- (b) From the Laki Limestone west of Ranikot, fairly high up in the massive limestone. Indian Geological Survey, K 6/926 and K 7/869.
- (c) From the Laki Limestone, 5 miles south by east of Bund Vera. Indian Geological Survey, 280,86.
- (d) A small form of this species, with a length of 2 to 3 mm., is common in the Upper Ranikot Series, immediately below the terrace forming the limestone-band on which the town of Jerruck (Sind) is situated.

Genus Assilina A. d'Orbigny.

Assilina Granulosa E. J. A. d'Archiae. (Pl. XXVI, figs. 1-5.)

- 1853. Nummulites granulosa D'Archiac & Haime (2 b) pars.
- 1853. Operculina tattaensis D'Archiac & Haime (2 c). 1919. Assilina granulosa D'Archiac & Haime, Douvillé (22 c).

D'Archiac & Haime, in their well-known monograph on the Indian fossils, have recorded this species from Kalibag in the Punjab and from the Hala Range (very rare). It is not clear whether any of their figures refer to the Indian forms (see Thévenin, 58) and the types are no longer preserved in the Musée de Paléontologie at Paris. Prof. Douvillé has done much to rectify the nomenclature of this species, and it is evident that D'Archiac confused it with A. exponens Sowerby. It is important that the differences between these species should be recognized, as A. granulosa is characteristic of the Lower Eocene (Laki of India), and A. exponens of the Middle Eocene (Kirthar of India), this distribution being established as practically the same by Douvillé in Southern France (22 c). Unfortunately, Sowerby's original diagnosis of A. exponens from Cutch (56) is incomplete, and the characteristics of the type of the species from India have so far never been adequately described. A. exponens and A. granulosa of Sind, Baluchistan, and Cutch can be distinguished by the following characteristics:—

(a) Size.—A. exponens, when adult, attains a greater diameter than A. granulosa. For the former a diameter of 15 to 20 mm. is common, and for the latter 15 mm. is the greatest that I have observed, the average being about 7 mm. The megalospheric forms which accompany the two species are distinct. A. mamillata (the megalospheric form of A. exponens) has an average diameter of 6 to 7 mm. A. leymerici (the megalospheric form of A. granulosa) measures usually about 2 to 3 mm. in diameter.

As regards thickness, A. exponens is more globose than A. granulosa. It is thicker in the centre than near the periphery, whereas A. granulosa usually is practically uniform in thickness from the centre to the periphery. This point has been made clear by Dr. Heim (37) in his description of the Swiss representatives of the two species, and is best observed by cutting a transverse section, which shows clearly that there is a greater thickening of the lateral laminæ near the centre of Assilina exponens than in A. granulosa. Among the Indian specimens both species are found with a central

depression.

(b) Granulations.—Among the Indian forms A. granulosa presents greater variability in number and prominence of granulations on the surface. Prominent granulations arranged concentrically on the exterior of the lamine of the whorl are common in young forms, and often adult specimens are smooth (compare Pl. XXVI, figs. 1 & 2, from the same locality). A. exponens shows similar but smaller granulations, which are practically uniform in size at all stages of growth. In the megalospheric forms A. mamillata is generally fairly smooth, and A. leymerici possesses large prominent granules (see Pl. XXV, fig. 8).

(c) Internal structure.—By cutting equatorial sections of the test, it has been observed that distinct differences exist in the Indian forms of A. exponens and A. granulosa. A. exponens (and mamillata) have septa which are most often nearly straight, so as to form rectangular chambers. A. granulosa (and leymeriei) have septa which join the inner margin of the chamber at practically a right angle, and usually are considerably curved near the exterior margin. The whorls are closer together in the typical A. exponens than in A. granulosa. In A. exponens the first six whorls are in a radius of 1.75 to 2 mm. and in A. granulosa in a radius of 2.25 to 3.5 mm. In a radius of 5 mm. there are ten whorls in A. exponens have ten whorls, and those of A. granulosa six to eight. Starting from the second whorl, the following figures give the number of septa in one quarter of a whorl:—

	A.	exponens.	A. granulosa.
2nd whorl	L	4-5	4-6
3rd do.		4-5	6-8
4th do.		. 6	7-9
5th do.		7	8-10
6th do.		8	9-12
7th do.		9	10-12
8th do.		9-11	14
9th do.	****************	11-12	
10th do.	******	14	

From these figures it will be observed that A. granulosa has

more septa than A. exponens.

As regards the megalospheric forms in India, the primordial chamber is single in A. mamillata with an average diameter of 0.5 mm. In A. leymeriei the primordial chamber (which is smaller) is compound, as has been described by Douvillé (22 d). There are usually six to seven whorls in A. mamillata and four in A. leymeriei.

(d) Stratigraphical distribution.—A. exponens is found throughout the Lower and Middle Kirthar Series. The lowest horizon from which I have specimens of a small globose form of this species is in the Ghazij Shales, 600 feet above the Dunghan Limestone of the Sham Plain, Bugti Hills (Baluchistan), where it

is found together with Assilina granulosa. A. granulosa ranges from the base of the Meting Limestone to the top of the Ghazij Shales, in other words, through the whole Laki Series.

Description of Varieties of Assilina granulosa from the Laki Series.

D'Archiac made a separate species, Operculina tattaensis, of a small form of Assilina described by Carter in 1853 (2 c, 9 c) occurring 'in company with Alveolina, near the town of Tatta.' I have collected specimens from the scarp of Meting Limestone west and south of Tatta (see Pl. XXVI, figs. 3 & 4), and it is clear that this is only a small, usually almost smooth variety of A. granulosa, as has already been pointed out by Vredenburg (59 a).

The specimens of A. granulosa that I have figured were collected from the Meting Limestone of Lower Sind, and from the Ghazij Shales of the Bolan Pass (Baluchistan). It will be observed that the species shows considerable variation, and on the whole the adult form is thinner and less granular than the typical European representative of the species. To use Douvillé's term in describing regional varieties of one species, the Indian forms belong to a different 'race' of A. granulosa from those found in Europe, but they are not sufficiently different to be separated as a variety.

The specimens from the Meting Limestone near Tatta vary from 10.4 to 6.2 mm. in diameter and 1.4 to 1.0 mm. in thickness, the average ratio of diameter to thickness being 6.5.1. Granulations usually are only present near the centre, and are universal in young forms, where they are large and prominent. There are,

as a rule, about six whorls.

Forms of A. granulosa from the Ghazij Shales of the Bolan Pass (Pl. XXVI, figs. 1, 2, & 5) show a larger adult development than those of Lower Sind. This character may be due to better nutrition or more favourable conditions, and is not considered sufficient for classifying the specimens from near Tatta as a distinct variety. The diameter of the test of the specimens from the Bolan Pass varies from 15.6 to 4.6 mm. and the thickness from 1.6 to 1.0 mm. Young forms are as a rule coarsely granulate, as illustrated in Pl. XXVI, fig. 2; and the adult forms are nearly smooth, showing externally the septa, as in Pl. XXVI, fig. 1.

Occurrence.

(a) From the Meting Limestone and Meting Shales, in the neighbourhood of Meting (Sind).

(b) From the Meting Limestone of the Mukli Hills, on the road from Tatta to Jungshahi, and 7 miles south-south-west of Tatta (Sind).

 (c) From the Laki Limestone, west of Bund Vera Plain, near Murid (Sind).
 (d) From the Ghazij Shales, Shero Kund Nala, west of Trigonometrical Station 3365, west of Bibi Nani, Bolan Pass (Baluchistan).

(e) From the base of the Ghazij Shales, immediately above the Dunghan Limestone, north-east of Trigonometrical Station 1485, Garai Nala, west of Gokurth, Bolan Pass (Baluchistan).

(f) From the Dunghan Limestone, Fort Munro (Baluchistan border).

(g) From the Ghazij Shales of the Sham Plain, Bugti Hills (Baluchistan).

From about 600 feet above the Dunghan Limestone, collected by
Mr. D. Dale Condit, of the Whitehall Petroleum Corporation.

Assilina leymertei (D'Archiac & Haime). (Pl. XXV, fig. 8.)

1853. Nummulites leymeriei D'Archiac & Haime (2 d).

This species is the megalospheric form of A. granulosa, in association with which it occurs. It has been recorded from Sind and the Punjab by D'Archiac & Haime (2e), and the more important characteristics of the species have been discussed above.

Genus Nummulites Lamarck.

NUMMULITES ATACICUS Leymerie. (Pl. XXV, figs. 1–6.)

1844. Nummulites atacicus Leymerie (40 c). 1853. Nummulites biarritzensis D'Archiac & Haime, pars (2 f). 1911. Nummulites atacicus Leymerie, Boussac (5 a).

1919. Nummulites atacicus Leymerie, Douvillé (22 e).

This well-known species, with an extensive distribution, has a wide stratigraphical range in India, extending from the Meting Limestone at the base of the Laki Series up into the Kirthar Beds, and is not limited to the Laki Series, as has been stated by Vredenburg (59). For the present, I will only submit palæontological

details of specimens from the Laki Series.

The septal filaments show great variation. In the young specimens they are always nearly straight radiate (as in Pl. XXV, fig. 6). In specimens that are about half developed the septal filaments are usually gently sinuate, as in figs. 4 & 5, and the type with a median curvature (as in fig. 3) is uncommon. In adult forms they present irregularities, as is characteristically shown in figs. 1 & 2, but appear never to be as meandriform as in some European varieties, such as have been described by Prof. Douvillé (22 f). In all the specimens the edge possesses a fairly sharp keel.

The internal structure of the Indian representatives of the species is similar to that of European forms described by De la Harpe (32, 33, 34), Prever (51), and others. The Indian Laki specimens that I have examined have the following variations in size and internal development. The average diameters of usually ten specimens from localities lettered f, e, b, & c in the list on p. 445 are 12.8, 10.7, 9.1, and 6.3 mm., the average of these being 9.7 mm. The maximum diameter observed was 16.7 mm. The thickness of the specimens from the same localities in the same order was 4.1, 4.0, 3.5, and 2.6 mm., the average of these being 3.5 mm. The greatest width observed was 5.5 mm. The ratio of thickness to diameter varies from 1:2.5 to 1:3.1.

The number of whorls varies from eight to nine in the first 3 mm. of radius. The greatest number of whorls observed was eighteen in a radius of 7 mm. The number of septa in one quarter of a convolution in successive whorls is as follows:-

3rd	whorl $(\frac{1}{4})$) number	of septa	***********	5 to 6
$4 ext{th}$	99	23	,,		6 to 9
5th	,,	99	99		6 to 10
6th	22	22	55		8 to 10
7th	22	,,	99		8 to 13
8th	27	53	9.9		9 to 14
9th					11 to 14

Occurrence.

(a) From the Meting Limestone, a mile and a half north-east of Meting.

(b) From the Meting Limestone, 7 miles south-south-west of Tatta (Sind).
 (c) From the Meting Limestone, Mukli Hills, on the road from Tatta to Jungshahi.

(d) From the Laki Limestone, 5 miles south-east of Bund Vera. Indian

Geological Survey No. 280/86.

(e) From the base of the Ghazij Shales, immediately above the Dunghan Limestone, north-east of Trigonometrical Station 1485, Garai Nala, west of Gokurth, Bolan Pass (Baluchistan).

(f) From the Ghazij Shales, Shero Kund Nala, west of Trigonometrical

Station 3365, west of Bibi Nani, Bolan Pass (Baluchistan).

(g) From the Dunghan Limestone, Parri Nala, west of Bibi Nani, Bolan Pass (Baluchistan).

NUMMULITES SUBATACICUS Douvillé. (Pl. XXV, fig. 7.)

1919. Nummulites subatacicus Douvillé, et syn. (22 g).

This species, which is found associated with N. atacicus, is the megalospheric form. The diameter of the Indian Laki specimens varies from 5·0 to 2·5 mm., and the thickness from 2·5 to 1·3 mm., the average ratio of diameter to thickness being 2:1. It possesses from four to five whorls. The primordial chamber is usually double, as has been described by Douvillé, but is also found single with a diameter of 0·2 mm. The septal filaments are about six to ten in number in one quadrant, and usually are gently curved.

NUMMULITES MAMILLA Fichtel & Moll (?). (Pl. XXVII, figs. 1-3.)

1924. ? Nummulites mamilla Fichtel & Moll, Douvillé (25 a).

A small radiate megalospheric nummulite, with an apical mamelon. is abundant at certain horizons in the Meting and Laki Limestones. In the Laki Limestone of Murid, in the Bund Vera plain, the microspheric form of the species is absent. In the Meting Limestone near Meting this nummulite is found, together with N. atacicus and N. subatacicus, and it would appear merely to be a variety of the latter species, distinguished by having a mamelon. There is a single median pustule, with nearly straight, simple, radiate septal filaments, which number about seven in one quadrant. The diameter of the test varies from 2.8 to 1.7 mm., and the thickness from 1.7 to 1.0 mm. The average ratio of diameter to thickness is 1.8:1, and there are from three to five whorls. The primordial chamber is commonly single, when it has a diameter of about 0.2 mm., and is also found double (as in Pl. XXVII, fig. 3).

In Europe Nummulites mamilla is considered by Prof. Douvillé to be a variety of N. guettardi. It accompanies N. globulus (the microspheric form), which I have not observed in India. The above specimens from India are not easy to identify, as several small species of megalospheric nummulites are found which are very difficult to distinguish unless the accompanying microspheric

form is present.

Occurrence.

(a) From the Meting Limestone, a mile and a half north-east of Meting.

(b) From the Laki Limestone, near Murid, Bund Vera Plain (Sind).(c) From the Dunghan Limestone, Fort Munro (Baluchistan Border).

NUMMULITES IRREGULARIS Deshayes. (Pl. XXVI, figs. 6 & 7.)

1838. Nummulites irregularis Deshayes (17). 1853. Nummulites irregularis Deshayes, D'Archiac & Haime (2 g). 1883. Nummulites irregularis Deshayes, De la Harpe (35 a).

1911. Nummulites irregularis Deshnyes, Boussac (5 b). 1919. Nummulites irregularis Deshayes, Douvillé (22 h).

I have found only the microspheric form of this species in the Laki Series of the Bolan Pass (Baluchistan). The forms obtained here vary in diameter from 22.5 to 12.5 mm., the average diameter being 18 mm., and the thickness ranges from 1.8 to 2.5 mm. The ratio of diameter to thickness is about 7:1. On the exterior the septal filaments are often less strongly marked than in the figured specimen, and also it is not uncommon to find the last whorl demarcated by a low ridge in its interior border. This last characteristic is very accentuated in specimens figured by Ph. de la Harpe from Switzerland (35 b) and by Douvillé from Southern France (22 i). Internally, the inclination and number of septa are variable. Sometimes they are strongly curved, as in Pl. XXVI, fig. 7, and in other specimens but slightly bent. The number of whorls is six, in a radius of 6 to 8 mm.

Occurrence.

(a) From the base of the Ghazij Shales, immediately above the Dunghan Limestone, north-east of Trigonometrical Station 1485, west of Gokurth, Bolan Pass (Baluchistan).

(b) From the Dunghan Limestone, Parri Nala, west of Bibi Nani, Bolan

Pass (Baluchistan).

Genus Orbitoides A. d'Orbigny. Subgenus DISCOCYCLINA Gümbel.

DISCOCYCLINA ARCHIACI (Schlumberger) var. BALUCHISTANENSIS nov. (Pl. XXVII, fig. 8.)

1903. Var. of Orthophragmina archiaci Schlumberger (53).

1922. Var. of Discocyclina archiaci Schlumberger, Douvillé (23).

An Indian variety of this species occurs at the base of the Ghazij Shales, north-east of Trigonometrical Station 1485, Garai Nala, west of Gokurth, Bolan Pass (Baluchistan). The diameter of specimens from this locality varies from 5 to 13 mm. and the thickness from 1 to 2 mm. This form is closely related to D. archiaci from the Ypresian and Lower Lutetian of France. The development of the pillars in the lateral portion of the test is practically identical with that of D. archiaci, as described and figured by Prof. H. Douvillé. The columns, which are circular in cross-section, have a diameter of 70 to 100 \mu, and are surrounded by a rosette of five to eight petals. The mesh of the network is from 70 to 100 μ .

In shape the variety differs from typical Discocyclina archiaci, which is flat and lenticular. The Indian variety has a distinct mamelon, and may be regular in shape, as in Pl. XXVII, fig. 8, but more often small saddle-shaped forms are found with narrow margins, which have been broken in the specimens that I have examined. I have obtained an equatorial cross-section of

Fig. 5.—Horizontal cross-section of Discocyclina archiaci var. baluchistanensis, showing the megalosphere.



a megalospheric individual, which shows a very unusual primordial chamber (fig. 5). The first chamber is not preserved, the whole central portion being filled with clear crystallized calcite, but the outer embracing chamber exhibits a very irregular outline. Its length is 1.4 mm. and the width 0.6 mm., very different from the dimensions of the second chamber of a typical D. archiaci, which is sub-

circular in cross-section with a diameter of 0.4 mm. Surrounding the primordial chamber, the cells of the first whorl in the median plane are nearly square. They become much more elongate towards the periphery.

Genus Orbitolites Lamarck.

ORBITOLITES COMPLANATA Lamarck.

1801. Orbitolites complanata Lamarck (39).

1916. Orbitolites complanata Lamarck, Douvillé (21 d et syn.).

This well-known species occurs abundantly in the Laki Series, being particularly common in the Meting Limestone, and rare in the Kirthar Series. The diameter of the specimens from Sind ranges from 5 to 35 mm., the average diameter being about 17 mm. I have examined specimens of this fossil from the following localities:—

- (a) From the Meting Limestone, north-east and south-east of Meting (Sind).
- (b) From the Dunghan Limestone, Parri Nala, Bolan Pass (Baluchistan).
 (c) From the Dunghan Limestone, Fort Munro (Baluchistan Border).
 British Museum (Natural History) No. P 9741.

(d) From the Laki Limestone, north of Meting.

- (e) From the Laki Limestone, 5 miles south-east of Bund Vera (Sind).
 Indian Geological Survey, No. 280/86.
- (f) From the Middle Kirthar Limestone, south-east of Damach, Thana Bula Khan Taluqa, Karachi District (Sind).

OPERTORBITOLITES gen. nov.

OPERTORBITOLITES DOUVILLÉI Sp. nov. (Pl. XXVII, figs. 4-7.)

Generic characteristics.—Test circular, lenticular, consisting of a median chamber-layer resembling that of *Orbitolites*.

Superimposed on each side of the median chamber-layer is a thick

imperforate lamina of shell-substance.

Specific description.—Test circular, lenticular, with a smooth exterior. The central portion of the test=about 1 mm. in thickness, and the peripheral part=0.3 mm. Maximum observed diameter=11 mm.

The test consists of a median cell-layer, with a lamina of shell-substance above and below. When a thin horizontal section of the median cell-layer is examined (Pl. XXVII, fig. 7), it is observed that the cells are disposed in concentric annuli, and are arranged alternately, as in *Orbitolites complanata*. Near the periphery

there are about eleven cells per millimetre.

When viewed in transverse section (Pl. XXVII, figs. 4–6) the median cell-layer is thicker near the periphery than at the centre. The vertical septa, which are the bounding walls of the annular cells, are usually arched outwards, and are not sinuous in cross-section, as in O. complanata. The cells are vertically elongate-cylindrical, extending across the whole distance between the flanking laminæ, and since not infrequently the septa do not extend for the whole distance across the median cell-layer, it would appear that there was a lateral communication for the sarcode from cell to cell. I have obtained only one cross-section of the primordial chamber (Pl. XXVII, figs. 4 & 5), and the portion cut by this section is about 120 μ in width and 200 μ in length.

The flanking lamine above and below the median cell-layer are peculiar to the genus, being unknown in *Orbitolites* or related genera, and quite different from that of *Orbitolides* in being imperforate and without columns of cells. A very thin transverse section of this covering lamina shows that it is composed of translucent, amorphous, calcareous material, which (except for faint concentric lines, indicating successive lamine of growth) appears devoid of structure. In the central part of the test this lamina is

about 0.5 mm. thick, and near the periphery 60μ .

Material.—This fossil has so far only been found in a hard limestone, and all the knowledge as to its structure has been obtained by making thin sections of the rock. At present, owing to the lack of sufficient rock-material, I have been unable to obtain a section showing the disposition of the cells immediately surrounding the primordial chamber. There are other details of internal structure which can only be elucidated when more material is available.

Occurrence.—This species occurs in the Dunghan Limestone of Parri Nala, west of Bibi Nani, Bolan Pass (Baluchistan). In a single sample of rock obtained from this locality it is found associated with Alveolina subpyrenaica, A. ovicula, Flosculina globosa, and Nummulites atacicus. I have named the species after Prof. H. Douvillé, whose brilliant researches on the larger Foraminifera have been of great importance in establishing a satisfactory basis for the classification of the Tertiary System.

VII. BIBLIOGRAPHY.

ALTPETER, O.— Beiträge zur Anatomie & Physiologie von Alveolina' Neues

Jahrb. vol. xxvi (1913) pp. 98-104 & figures in series A-C

Archiac, E. J. A. d', & Haime, J.—' Animaux Fossiles du Groupe Nummulitique de L'Inde' 1853; (a) p. 182 & p. 348; (b) p. 151 partim, & pl. x, figs. 11, 16, 17; (c) p. 347 et syn.; (d) p. 153 & pl. xi, figs. 9-12; (e) p. 345; (f) p. 131 & pl. viii, fig. 5 (non 4? non 6); (g) pp. 138-39 & pl. viii, figs. 16-19.

(3)BLANFORD, W. T.—'The Geology of Western Sind' Mem. Geol. Surv. Ind.

vol. xvii (1879); (a) pp. 32 & 45-50; (b) pp. 144-45; (c) pp. 10, 147-54.

BLANFORD, W. T.—'Geological Notes on the Hills in the Neighbourhood of the Sind & Punjab Frontier between Quetta & Dera Ghazi Khan' Mem. Geol. Surv. Ind. vol. xx (1883) pp. 35, 46, & 72.

Boussac, J.—'Paléontologic du Nummultique Alpin' Mém. Carte Géol. (4)

détaillée de France, 1911: (a) pp. 28-32 & pl. ii, fig. 26, pl. iii, fig. 15, pl. v, fig. 14; (b) pp. 18-20 & pl. i, figs. 17, 21, 22; (c) p. 107.

Brady, H. B.— Report on the Scientific Results of the Challenger Expe-

(6)

dition' vol. ix (1884) pp. 223-24.

CARTER, H. J .- Geological Observations on the Composition of the Hills & (7) Alluvial Soil, from Hyderabad in Sindh to the Mouth of the River Indus Journ. Bombay Branch Roy. Asiat. Soc. vol. ii (1844) p. 41 & pl. viii, figs. 11 a-11 b.

CARTER, H. J.- On Foraminifera, their Organization & their Existence in a (8)Fossilized State in Arabia, Sindh, Kutch, & Kattyawar' Journ. Bombay Branch Roy. Asiat. Soc. vol. iii (1849) pp. 168-69 & pl. viii, figs. 2 a-2 b.

(9) CARTER, H. J.— Descriptions of some of the Larger Forms of Fossilized Foraminifera in Scinde; with Observations on their Internal Structure' Journ. Bombay Branch Roy. Asiat. Soc. vol. v (1853); also the same in Ann. Mag. Nat. Hist. ser. 2, vol. xi (1853): (a) p. 170 & pl. vii, fig. 16 [in this edition Tatta is misprinted [Yolta]; (b) p. 171 & pl. vii, fig. 17; (c) pp. 167-68 & pl. vii, figs. 3-4.

Carter, H. J.— On the True Position of the Canaliferous Structure in the Shell of Fossil Alveolina (D'Orbigny)' Ann. Mag. Nat. Hist. ser. 2, vol. xiv (1854) pp. 99-101 & pl. iii B, figs. 1-5.

Carter, H. J.— On the Fossil Foraminifera of Scinde' Ann. Mag. Nat.

Hist. ser. 3, vol. viii (1861) p. 380.

Checchia-Rispoli, G.—'I Foraminiferi dell' Eocene dei Dintorni di Marco La Catola in Capitanata' Palæontologia Italica, vol. xix (1913) pp. 108-109. CHECCHIA-RISPOLI, G.—'Sui Terziari Inferiori del Versante Settentrionale delle Madonie' Mem. Carta Geol. Italia, vol. vi (1916): (a) pl. ii, figs. 7 & 7 a; (b) p. 37.

Checchia-Rispoli, G.—'L'Eocene dei Dintorni di Roseto Valfortore & Considerazioni sulla sua Fauna' Boll. R. Com. Geol. Ital. vol. xlvi (1917) (14)

pp. 197-98.

(12)

(16)

COSSMANN, M., & PISSARRO, G.—'The Mollusca of the Ranikot Series' Mem. Geol. Surv. Ind. Palæontologia Indica, n. s. vol. iii, Mem. No. 1 (1909): p. 76 & pl. vi, figs. 24-27.

Dainelli, G.-- L'Eocene Friulano: Monografia Geologica & Paleontologica

1915, p. 167 & pl. xvi, figs. 9-10. Deshayrs, H. P—'Description des Coquilles recueillies en Crimée par M. DE Verneull' Mém. Soc. Géol. France, vol. iii (1838) p. 67 & pl. vi, (17)figs. 10-11.

DONCIEUX, L.—'Catalogue descriptif des Fossiles Nummulitiques de l'Aude & de l'Hérault: 1. Montagne Noire & Minervois' Ann. Univ. Lyon, n. s. 1. Sc. Médecine, Fasc. 17 (1905): (a) pp. 9-28 & pp. 111-27; (b) p. 122; (18)(c) p. 16; (d) pp. 125-26. Douvillé, H.— Evolution & Enchaînement des Foraminifères Bull. Soc.

(19)

Géol. France, sér. 4, vol. vi (1906) p. 585. Douvillé, H.—'Les Foraminifères des Couches de Rembang' Beiträge zur (20)Geol. Ost-Asiens & Australiens, Samml. Geol. Reichsmus. Leiden, ser. 1, vol. x, pt. 2 (1916) p. 32.

Douvillé, H.—'Le Crétacé & l'Eocène du Tibet Central' Mem. Geol. Surv. (21)Ind. Palæontologia Indica, n. s. vol. v, Mem. No. 3 (1916): (a) p. 42; (b) pp. 25-26 & pl. viii, figs. 1-3; (c) pp. 42-43 & pl. xvi, figs. 3-5; (d) p. 43 & pl. xvi, figs. 1-2.

Douvillé, H.—'L'Eocène Inférieur en Aquitaine & dans les Pyrénées' Mém. Carte Géol. détaillée de France, 1919 : (a) p. 21 ; (b) p. 73 & pp. 78-(22)79; (c) pp. 72-74 & pl. iv, figs. 15-17; (d) p. 75 & text-fig. 14; (e) pp. 88-41 & pl. iii, figs. 1-6; (f) p. 9; (g) pp. 41-43 & pl. iii, figs. 7-8 et syn.; (h) p. 68 & pl. v, figs. 22-29, pl. vi, fig. 4, pl. vii, figs. 1-2; (i) pl. vii, fig. 1; (j) p. 17; (k) p. 25; (l) p. 15.

DOUVILLÉ, H.—'Révision des Orbitoïdes'; Pt. 2, Bull. Soc. Géol. France,

sér. 4, vol. xxii (1922) pp. 65-66 & figs. 16-17

Douvillé, H.—'Le Nummulitique au Sud des Pyrénées' C. R. Acad. Sci. (24)Paris, vol. clxxiv (1922) pp. 507-10. Douvillé, H.—'Les Premières Nummulites dans l'Éocène du Béarn' C. R. (25)

Acad. Sci. Paris, vol. clxxviii (1924) pp. 36-41: (a) pp. 38-39. Duncan, P. M., & Sladen, W. P.—' Fossil Echinoidea of Western Sind'

(26)

Palsontologia Indica, ser. 14, vol. i, pt. 3 (1882-86).

Fabiani, R.—'Il Paleogene del Veneto' Mem. Ist. Geol. R. Univ. Padova, (27)

vol. iii (1915) table facing p. 178. Fabiani, R.—'Il Terziario del Trentino' Mem. Ist. Geol. R. Univ. Padova, (28)

vol. vi (1922) pp. 54-55.

FEDDEN, F .- On the Distribution of the Fossils described by Messrs. (29)D'Archiac & Haime in the different Tertiary & Infra-Tertiary Groups of Sind' Mem. Geol. Surv. Ind. vol. xvii (1879) p. 198.

Fornasini, C.—' Illustrazioni di Specie Orbignyane di Foraminiferi Istituite nel 1826' Mem. R. Acad. Sci. Bologna, ser. 6, vol. i (1904) p. 15 & (30)

fig. 11.

GRIESBACH, C. L .- 'Report on the Geology of the Section between the Bolan Pass in Baluchistan & Girishk in Southern Afghanistan' Mem. Geol. Surv. Ind. vol. xviii (1881) pp. 1-60: (a) p. 22.

HARPE, PH. DE LA.—'Nummulites des Alpes Françaises' Bull. Soc. Vaud. Sci. (32)

- Nat. vol. xvi (1879) pp. 415-16. Навре, Рн. de la.—' Description des Nummulites des Falaises de Biarritz' Bull. Soc. Borda à Dax, vol. v (1880) p. 68 & fig. 1; vol. vi (1881) pp. 29-37.
- HARPE, PH. DE LA.—'Monographie der in Ægypten & in der Lybischen Wüste vorkommenden Nummuliten' Palæontographica, vol. xxx (1883) (34)pp. 168-70 & pl. xxx, figs. 19-28. Harpe, Ph. de la.—'Nummulites de la Suisse: pt. 3' Mém. Soc. Pal.
- Suisse, vol. x (1883): (a) p. 154 & pl. iv, figs. 16-34, pl. v. figs. 1-2; (b) pl. iv, fig. 16.

 HAUG, E.—'Traité de Géologie' 1908-11, p. 1430 & pl. cxxii.

 HEIM, A.—'Die Nummuliten & Flyschbildungen der Schweizeralpen'

(36)

(37)Abhandl. Schweiz. Pal. Gesellsch. vol. xxxv (1908) pp. 242-51.

JONES, T. R. - Catalogue of Fossil Foraminifera in the British Museum (38)

(Natural History)' 1882. p. 61. LAMARCK, J. B. DE.—'Système des Animaux sans Vertèbres' 1801, p. 376. (39)LEYMERIE, A.—' Mémoire sur le Terrain à Nummulites des Corbières & de la (40)Montagne Noire' Mém. Soc. Géol. France, sér. 2, vol. i (1844): (a) p. 359 & pl. xiii, figs. 9 a-9 c; (b) p. 359 & pl. xiii, figs. 10 a-10 c; (c) p. 358 &

pl. xiii. figs. 13 α -13 e. Loftus, W. K.—'On the Geology of Portions of the Turko-Persian Frontier (41)and Districts adjoining' Q. J. G. S. vol. xi (1855) pp. 276-77

NETLING, F.- On the Occurrence of Velates schmideliana Chem. & Pro-(42)velates grandis Sow. sp. in the Tertiary of India & Burma ' Rec. Geol. Surv. Ind. vol. xxvii (1894) pp. 103-107 & pls. i-ii. Nœtling, F.—Centralblatt für Mineralogie, Geologie & Paläontologie,

(43)

1903, p. 521; ibid. 1905, pp. 135 & 170.

OLDHAM, R. D.—'Report on the Geology & Economic Resources of the (44)Country adjoining the Sind-Pishin Railway between Sharigh & Spintangi, & the Country in between it & Khattan' Rec. Geol. Surv. Ind.

vol. xxiii (1890) pp. 93-109: (a) p. 94.

OLDHAM, R. D.—' Report on the Geology of Thal Chotiali & part of the Mari Country' Rec. Geol. Surv. Ind. vol. xxv (1892) pp. 18-29: (a) (45)

pp. 21-23.

(46)Orbigny, A. D'.- Tableau Méthodique de la Classe des Céphalopodes 'Sci. Nat. vol. vii (1826): (a) p. 306, No. 3; (b) p. 306, No. 4.

Orbigny, A. D'.- Fossiles Foraminifères du Bassin Tertiaire de Vienne' (47)1846, p. 146.

- (48) Osimo, G.- Studio Critico sul Genere Alveolina D'Orb.' Palæontologia Italica, vol. xv (1909); (a) p. 83; (b) p. 89 & pl. vi (iii), figs. 13-18; (c) p. 90.
- (49)PARKER, W. K., & JONES, T. R .- 'On the Nomenclature of Foraminifera' Ann. Mag. Nat. Hist. ser. 3, vol. viii (1861) p. 164.
- PILGRIM, G. E.—'The Vertebrate Fauna of the Gaj Series in the Bugti Hills & the Punjab' Palæontologia Indica, n. s. vol. iv, Mem. No. 2 (1912): (50)
- geological map. Prever, P. L.—'Le Nummuliti della Forca di Presta, nell' Appennino Centrale & dei Dintorni di Potenza nell' Appennino Meridionale' Mém.
- Soc. Pal. Suisse, vol. xxix (1902) p. 74 & pl. iv, figs. 7-8.

 RUTTEN, L. M. R.—'Die Altmiocäne Fauna des West-Progogebirges auf
 Java' Samml. Geol. Reichsmus. Leiden, n. s. vol. xi (1917) pp. 276-77.

 SCHLUMBERGEE, C.—'Troisième Note sur les Orbitoïdes' Bull. Soc. Géol. (52)
- France, sér. 4, vol. iii (1903) p. 277 & pl. viii, figs. 5-7, 11. Schubeet, R. J. [in P. S. Richarz].— Der Geologische Bau von Kaiser-(54)Wilhelmsland nach dem heutigen Stand unseres Wissens.' Neues Jahrb.
- Beilage-Band xxix (1910) p. 533. Schwager, C.—' Die Foraminiferen aus den Eocänablagerungen der Libyschen Wüste & Ægyptens' Palæontographica, vol. xxx (1883): (a) p. 102;
- (b) p. 98 & pl. xxv (ii), figs. 3 a-3 g. Sowerby, J. de C.—' Description of the Fossils to illustrate Col. Sykes's (56)Paper on Fossils procured by Capt. SMEE & Col. POTTINGER in Cutch, &c.' Trans. Geol. Soc. Lond. ser. 2, vol. v (1837–40) pl. lxi, figs. $14\,\alpha$ – $14\,f$: forms A & B.
- SOWERBY, J. DE C .- 'Fossils collected by Capt. GRANT in Cutch' Trans. (57)
- Geol, Soc. Lond. ser. 2, vol. v (1837-40) pl. xxiv, figs. 17 & 17 a.

 Thevenin, A.—'Les Echantillons de la Monographie des Nummulites de (58)
- D'Archiac' Bull. Soc. Géol. France, sér. 4, vol. iii (1903) p. 264.

 Verdenburg, E.—'Nummulités Douvilléi, an Undescribed Species from Kach, with Remarks on the Zonal Distribution of Indian Nummulites' (59)
- Rec. Geol. Surv. Ind. vol. xxxiv (1906) pp. 78-95: (a) p. 86; (b) p. 94. Veedenburg, E.— The Classification of the Tertiary System in Sind, with (60)reference to the Zonal Distribution of Eocene Echinoidea described by Duncan & Sladen' Rec. Geol. Surv. Ind. vol. xxxiv (1906) pp. 172-98: (a) p. 178; (b) p. 189; (c) p. 186. Veldenburg, E.—'Introductory Note on the Stratigraphy of the Ranikot
- (61)Series, in 'The Mollusca of the Ranikot Series' by Cossmann & Pissarro, Mem. Geol. Surv. Ind. Palæontologia Indica, n. s. vol. iii, Mem. No. 1 (1909) pp. v-xix: (a) Table facing p. vi, pp. x-xii; (b) geological map,
- VREDENBURG, E.- 'Pseudo-Fucoids from the Pab Sandstones at Fort Munro, (62)& from the Vindhyan Series' Rec. Geol. Surv. Ind. vol. xxxvi (1908) pp. 243-46.
- VREDENBURG, E .- 'Note on the Marine Fossils collected by Mr. PINFOLD (63)Rec. Geol, Surv. Ind. vol. li (1921) p. 325. in the Garo Hills'
- ZITTEL, K. A. von.— Beiträge zur Geologie & Paläontologie der Libyschen (64)Wüste, &c.' Palæontographica, vol. xxx (1883) pp. 96-112.

EXPLANATION OF PLATES XXIII-XXVII.

PLATE XXIII.

- Fig. 1. ×7.5. Thin section of Meting Limestone, from 5 miles north-east of Meting (Sind). The specimen at the top left-hand corner and the two lower forms on the right edge are Flosculina globosa Leymerie, the remainder being Alveolina subpyrenaica Leymerie.
 - 2. ×7.5. Thin section of Laki Limestone from the west side of Bund Vera Plain, near Murid (Sind): Alveolina subpyrenaica.
 - 3. ×5. Thin section of Meting Limestone from the same locality as in fig. 1. Alveolina subpyrenaica. (See p. 434.)
 4. ×5. Exterior view of Flosculina globosa. Meting Limestone, near
 - Meting (Sind). (See p. 435.)

PLATE XXIV.

- Figs. 1 & 2. ×16. Thin sections of Dunghan Limestone from Parri Nala, west of Bibi Nani, Bolan Pass (Baluchistan). Alveolina lepidula Schwager. In the right-hand top corner of fig. 2 is a Triloculina.
- Fig. 3. ×6.5. Longitudinal section of Alveolina subpyrenaica Leymerie, from Barroubio in the Montagne Noire, France. (For comparison.)
- Figs. 4, 5, & 6. ×5. Thin sections of Flosculina globosa Leymerie from the Meting Limestone, near Meting (Sind). Fig. 4. Section cut longitudinally, but not passing through the primordial chamber. Fig. 5. Oblique section. Fig. 6. Longitudinal section.

7 & 8. ×5. Thin longitudinal sections of Alveolina oblonga A. d'Orbigny, from the Meting Limestone, near Meting. (See p. 440.)

9 & 10. ×8. From the base of the Ghazij Shales immediately above the Dunghan Limestone, Parri Nala, west of Bibi Nani, Bolan Pass (Baluchistan). Fig. 9. Thin longitudinal section of Alveolina ovicula sp. nov. Fig. 10. Polished surface of A. ovicula sp. nov. Holotype. (See p. 439.)

PLATE XXV.

Figs. 1-6. Nummulites atacicus Leymerie (see p. 444), showing variations in the septal filaments, from the following localities:-

Figs. 1 & 4. ×5. From the base of the Ghazij Shales immediately above the Dunghan Limestone, north-east of Trigonometrical Station 1485, Garai Nala, south of Gokurth, Bolan Pass (Baluchistan).

2 & 3. ×5. From the Meting Limestone, 7 miles south-

south-west of Tatta (Sind).

Fig. 5.: ×5 · From the Meting Limestone of the Mukli Hills. on the road from Tatta to Jungshahi (Sind).

6. ×10. Young specimen. From the Laki Limestone, 5 miles south-east of Bund Vera. Indian Geological Survey, No. 280/86.

Fig. 7. ×10. Nummulites subatacious Douvillé. From the same locality

as the specimen illustrated in fig. 1. (See p. 445.)

8. ×5. Assilina leymeriei D'Archiac & Haime. From the Meting Limestone, Mukli Hills, on the road from Tatta to Jungshahi (Sind). (See p. 444.)

PLATE XXVI.

Figs. 1 & 2. ×5. Assilina granulosa D'Archiac. From the Ghazij Shales, Shero Kund Nala, west of Trigonometrical Station 3365, Bolan Pass (Baluchistan). (See p. 441.)

3 & 4. ×5. Assilina granulosa. From the Meting Limestone, 7 miles

south-south-west of Tatta (Sind).

Fig. 5. ×5. Assilina granulosa. From the base of the Ghazij Shales north-east of Trigonometrical Station 1485, Garai Nala, west of Gokurth, Bolan Pass (Baluchistan).

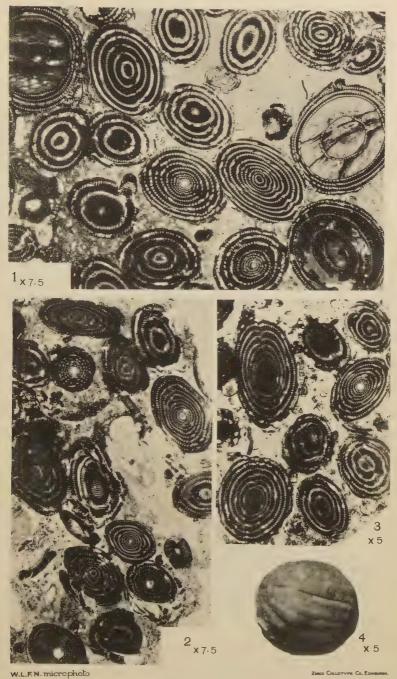
6. ×4. Nummulites irregularis Deshayes. From the same locality

as the specimen illustrated in fig. 5. (See p. 446.)

7. ×5. Nummulites irregularis. From the same locality as the specimen illustrated in fig. 6. Thin equatorial section showing septa and chambers.

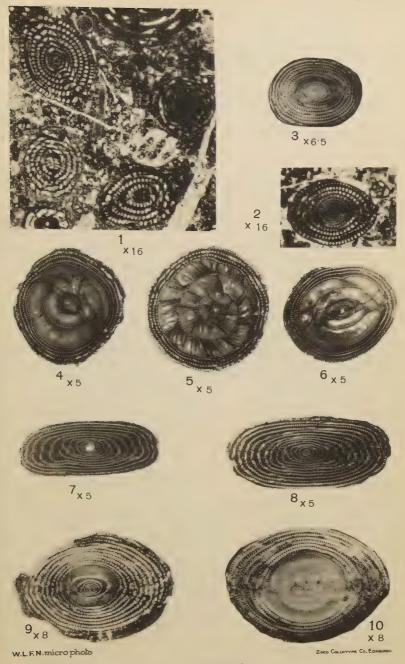
PLATE XXVII;

Figs. 1-3, ×10. Nummulites mamilla Fichtel & Moll? (see p. 445). Fig. 1. From the Meting Limestone, a mile and a half north-east of Meting. Figs. 2 & 3. Thin section of Laki Limestone, on the west side of Bund Vera Plain, near Murid; the same rock as in Pl. XXIII, fig. 2.



ALVEOLINÆ.

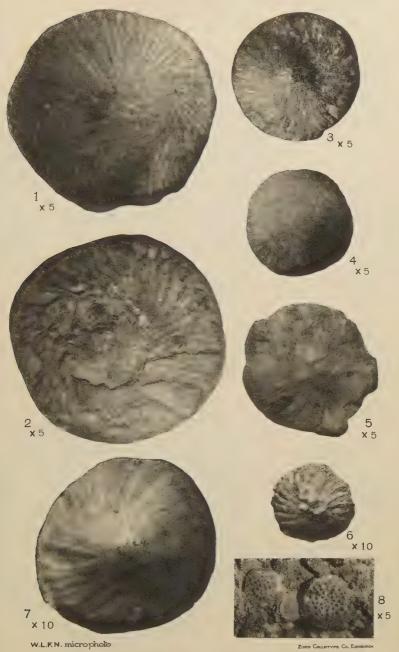




ALVEOLINÆ .



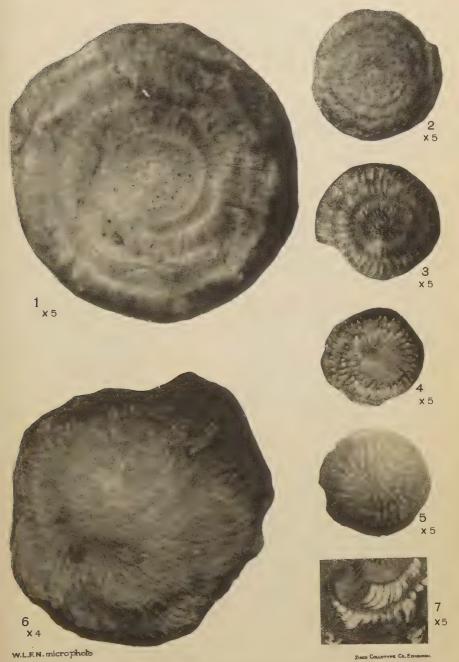
QUART. JOURN. GEOL. Soc, Vol.LXXXI, PL.XXV.



NUMMULITES and ASSILINA.

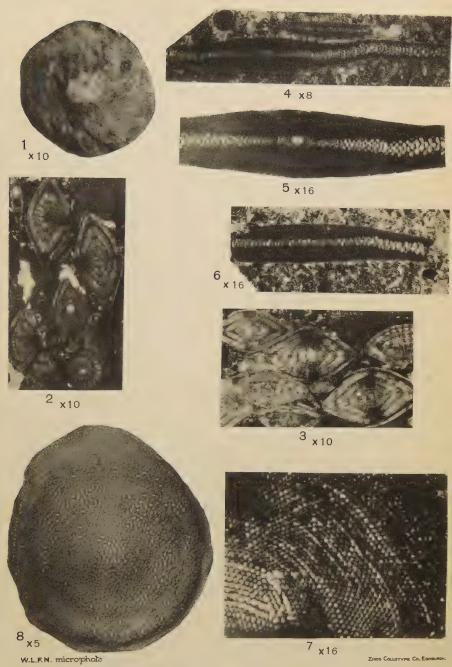


QUART. JOURN. GEOL. Soc, Vol. LXXXI, PL.XXVI.

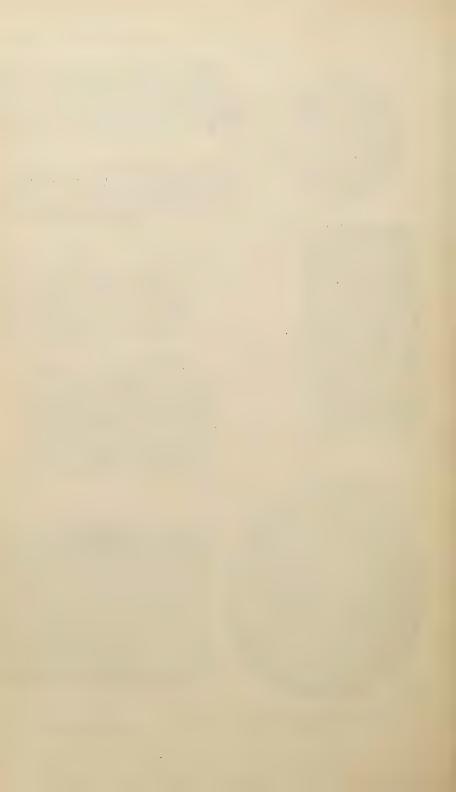


ASSILINA and NUMMULITES.





NUMMULITES, OPERTORBITOLITES nov. and DISCOCYCLINA.



Figs. 4-7. Opertorbitolites douvilléi gen. et sp. nov. (see p. 447) Fig. 4, ×8: Transverse section. Holotype. Fig. 5, ×16: The central portion of the same section as in fig. 4, magnified. Fig. 6, ×16: Transverse section. Fig. 7, ×16: Horizontal section, showing chambers in the median plane. All the specimens are from the Dunghan Limestone, Parri Nala, west of Bibi Nani, Bolan Pass (Baluchistan). The same rock as that illustrated in Pl. XXIV, fig. 1.

Fig. 8. ×5. Discocyclina archiaci Schlumberger, var. baluchistanensis nov. (see p. 446). Same locality as the specimen illustrated in

Pl. XXVI, fig. 5. Holotype.

DISCUSSION.

Dr. A. M. Davies expressed his sense of the value of the paper, but suggested caution as to the transference of the Laki from Middle to Lower Eocene, several of the foraminifera quoted being characteristic Lutetian species. He also suggested that the excessive thickening of the test in Flosculina (repeated in the Miocene Flosculinella) might be a phylogerontic feature, rather than an effect of environment, seeing that normal forms of Alveolina were found in the same rock with the thickened Flosculina.

Mr. R. D. Oldham also spoke.

The Author, in reply to Dr. Davies, said that he had observed another species of Alveolina in which the thickening of the shell-wall was variable, the foraminifer thereby exhibiting transitional stages from a characteristic Alveoline to a typical Flosculine. This species is A. elliptica Sowerby, which occurs in the Kirthar Series of Baluchistan, Cutch, and Assam. The type of A. elliptica with no thickening of the shell-wall is found in all three localities, and the varieties showing Flosculine tendencies only in Cutch. In this instance the Flosculine variety has a more limited geographical distribution in India than the type of the Alveoline.

With regard to the exact age of the Laki Series, more light would be thrown on this by an examination of the foraminifera of the underlying Ranikot Series and the overlying Kirthar Series. The Author was studying faunas from these horizons, and hoped

at a later date to be able to publish his results.

He further mentioned that, during his geological reconnaissance of Sind, he had found Dr. W. T. Blanford's memoir of great assistance. As regards the conglomeratic Dunghan Limestone of Baluchistan, in some localities he had noticed it to contain angular fragments, which fact brought evidence against the supposition

that this formation was of concretionary origin.

The Author agreed that there appeared to be a paleontological break between the Dunghan Limestone and the Ghazij Shales. He considered that the difference in fauna between the two formations was rather one due to facies than due to age. The Dunghan Limestone (with abundant Alveoline) was deposited in relatively shallow water, and the Ghazij Shales (containing chiefly Nummulites and Assiline) were of deeper-water origin.

15. On the CLAY PEBBLE-BED of ANCON (ECUADOR). By CHARLES BARRINGTON BROWN, M.C., M.A., F.G.S., and ROBERT ASHLEY BALDRY, B.A., F.G.S. (Read March 25th, 1925.)

[PLATES XXVIII & XXIX.]

The clay pebble-bed was first noted by one of us (C. B. B.) in 1919. It was further examined, and part of the outcrop mapped by him in 1922, when its nature and origin were realized. Mr. A. J. Ruthven Murray completed the mapping later. The authors of this paper examined the bed again in 1923, when final conclusions

as to its mode of origin were reached.

The outcrop is limited in extent, covering not more than 21 square miles; the numerous small areas are separated by tracts of stratified beds. The best exposure is along the sea-cliffs of Ancon Bay, on the south of the Santa Elena Peninsula. This peninsula is at the northern extremity of the Gulf of Guayaquil, 70 miles west of the town of Guayaquil, and some 130 from the main Andean chain.

A typical hand-specimen shows polished rounded or subangular pebbles of harder clay embedded in a matrix of softer clay. The clay-pebbles' vary from the size of a pin's head up to pieces 2 or 3 inches in diameter, and in rare instances the larger ones themselves contain smaller clay-pebbles. They are easily picked out of the matrix, leaving a smooth polished cast covered by a film of iron-staining. Both pebbles and matrix are grey; the films

are grey, green, or brown.

In the mass, as in cliff-sections, the clay pebble-bed is seen to contain, in addition, big and partly rounded boulders of sandstone, foraminiferal limestone, and pebbly grit, 2 or 3 feet in diameter, isolated polished quartz-pebbles, a few broken fossils, pieces of calcareous concretions, and a few foraminifera. In some places occur masses of limestone many cubic yards in extent, composed of the remains of foraminifera, and in one cliff-section inland there is a large mass of conglomerate showing sheared boulders and pebbles, flow-structure of the finer material around them, and stringing-out of successively smaller fragments and isolated pebbles in the mass of the clay pebble-bed (see fig. 7, p. 459). The rock weathers into a uniform brown clay with scattered stones and boulders; but on a freshly uncovered surface, and in samples from boreholes, the small clay-pebbles with their polished iron-stained casts are easily recognizable.

The upper limit of the bed is usually well defined, a fraction of an inch dividing the true clay pebble-bed from regularly bedded and little disturbed alternations of sandstones and clays. In some instances, however, the clay-pebble facies is separated from the stratified series by a belt of highly contorted strata, in which

sandstone-beds are drawn out into lenticles and bent round into fantastic shapes. Often a thick and more resistant sandstone is found resting upon the day pebble-bed, giving to the junction, locally, the appearance of an unconformity. This upper limit has subsequently been faulted and folded with the overlying strata.

Associated with the clay pebble-bed are great lenticular masses of stratified material, many yards in length. At first, these were interpreted as portions of the overlying strata faulted down, but they are now considered as integral parts of the bed itself.

The lower limit is never seen in the sea-cliffs, the total thickness exposed being in the neighbourhood of 200 feet. From information obtainable from boreholes, however, the total thickness is found to vary from 550 to 900 feet. The typical clay-pebble facies is separated by bands of normal stratified material, the thickness and position of which varies from one borehole to another. The upper and lower limits show a rough parallelism to the bedding-planes, and the clay pebble-bed may almost be considered as a stratigraphical unit.

The clay pebble-bed is the result of a great overthrust in soft sandstones and clays of Tertiary age. That this conclusion as to its origin is the only possible one is clear from the following considerations:—

- (1) The absolute lack of stratification and the large size of the boulders in a clay matrix precludes the possibility of ordinary sedimentary accumulation. A conglomerate is seen to be so teased out, that its constituent materials are isolated in a matrix of the bed.
- (2) There is a slickensiding polish on the harder clay-pebbles, and a high polish on the isolated quartz-pebbles.
- (3) The upper limit transgresses the bedding-planes of the superincumbent strata.
- (4) In places there is a transitional stage where tearing-away of the sole of the upper block is visible.
- (5) Minor thrust-planes are seen branching from the main upper boundary.
- (6) Any other hypothesis would require faulting of extreme complexity to explain the included blocks of stratified material.

The smaller thrust-planes give the direction of the thrusting as from the east-south-east, and the foraminifera contained in the

clays show that the movements were post-Eccene.

On this view of the nature and origin of the bed, figs. 1 to 5 attempt to show the mechanism of the thrust, and to explain the contained masses of unconverted and undisturbed beds. Fig. 6 (p. 458) shows the relation of the bed to the parent mass of stratified rocks.

It should be noted that the character of the beds along the upper line of contact depends on the nature of the material forming

STRATIFIED CLAYS AND SANDSTONES FIG.I ORIGINAL THRUST PLANE FIG. 2 FORMATION OF LENS BY CONTINUATION OF THRUSTING, AND SHIFTING OF MAIN MOVEMENT TO UPPER PLANE SINCE THERE IS LESS FRICTION THERE ON ACCOUNT OF LESS LOAD. FIG. 3 CRUMPLING OF LENS TO FORM YERY DISTURBED STRATA AND, ULTIMATELY, CLAY PEBBLE BED. FORMATION OF NEW LENSES AND TRANSFERENCE OF MAIN THRUST MOVEMENT TO A HIGHER HORIZON

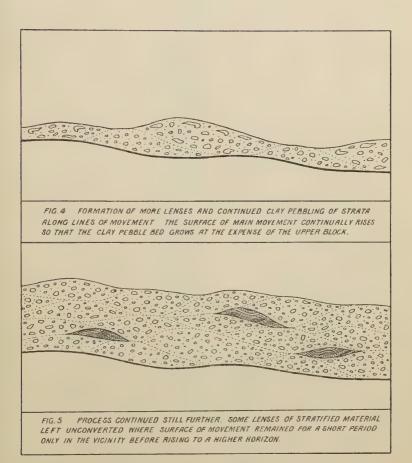
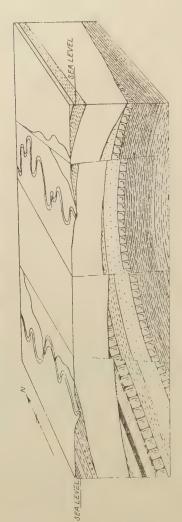
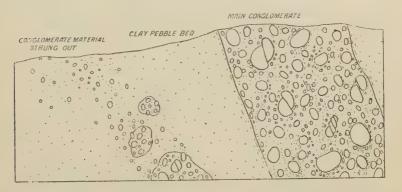


Fig. 6.—Diagram representing a perspective view of a block of country at Ancon, Santa Elena Peninsula (Ecuador).



sheet of non-stratified material of great thickness, varying from 550 to 900 feet, formed from the clays and sandstones of Tertiary age through the agency of a long-continued thrust from the south-east. The bed is shown unshaded in section. The stratification of the beds has been shown at an exaggerated [The nature of the clay pebble bed and its relation to the stratified rocks are here illustrated. This bed is a inclination to the clay pebble-bed, for the sake of clearness.] the sole of the upper block and the time during which the main surface of movement has coincided with its final position. Where a hard sandstone-band has formed the sole for a long time, it has in many places been left resting horizontally on a clean-cut surface of clay pebble-bed, the clays being crumpled by the movement while the sandstone remains rigid, giving locally the appearance of unconformity. At places where the surface of movement has only just jumped up to a higher horizon, undisturbed strata rest upon but slightly crumpled stratified rocks, with a crush-band along the thrust-plane. At other places, where movement has gone on a little longer, the lenticle below is crumpled and contorted, but stratification-lines can still be distinguished.

Fig. 7.—Mass of conglomerate in the clay pebble-bed, teased out into smaller boulders and isolated pebbles.



When the facts of the occurrence of the clay pebble-bed are reviewed, its significance is seen to be far-reaching. It indicates the presence of great thrusting movements in front of the Ecuadorian Andes in post-Eocene times, from land to sea, or the Brazilian block over the Pacific block. It illustrates the formation by thrusting of a thick stratum, difficult to differentiate from a stratigraphical unit or a boulder-clay. It gives an insight into the mechanism of overthrusting in soft strata: a thick breccia being formed by the tearing-away of portions from the sole of the upper block from time to time, leaving the latter horizontal and almost undisturbed. A similar rock-mass of great antiquity, which had been subjected to movement and metamorphism, would offer a problem impossible of solution; it is suggested that the present case may throw light on certain formations which have so far puzzled geologists.

EXPLANATION OF PLATES XXVIII & XXIX.

PLATE XXVIII.

Fig. 1. Hand-specimen of clay pebble-rock. Natural size.

 Clay pebble-bed; sea-cliff section, Ancon. The big boulder and the larger pebbles are of pebbly grit; other pebbles are of sandstone, while the smaller pebbles just visible in the photograph are of hard clay.

PLATE XXIX.

Fig. 1. Clay pebble-bed overlain by unconverted and undisturbed clays and sandstones; sea-cliff section, Ancon. Here the latest base of the thrust-plane is marked by a bed of massive sandstone, which has resisted disruption, and has doubtless slid over the underlying mass of clay pebble-bed for some distance.

 A lenticle of stratified clays and sandstones in a mass of clay pebblebed, which has been left unconverted on account of a rapid change of the surface of the thrust-plane to a higher level; sea-cliff section

shown. [The boundary is indicated by the broken line.]

DISCUSSION.

Mr. G. W. Lamplugh said that the brief description and diagrams of the Ecuadorian 'Pebble-Bed' seemed to show that it possessed many features in common with the crush-conglomerates of the Isle of Man, and, while of greater thickness, behaved similarly in its relationship to the bordering rocks. The Manx rocks were indurated before their brecciation, and it would be most interesting if the Ecuadorian bed proved to be an example of similar disintegration of soft rocks. A distinctive character of the crush-conglomerates known to the speaker was that their fragmental material was derived wholly from the associated strata. In the present case, it had not been made clear whether the limestone-masses of the conglomerate had their counterpart in the bordering stratified sequence. The paper would undoubtedly lead to further investigation and discussion.

Prof. V. C. Illing said that the description of the pebble-bed reminded the speaker of similar examples in Trinidad, where there was a zone of pebble-beds following a zone of thrusting. In this case, however, the pebbles were the result of shoal conditions produced penecontemporaneously with the thrusting, and not formed by the thrusts themselves. Such an origin might explain the peculiar conditions described in the paper more reasonably than

the theory presented by the Authors.

Dr. J. A. Douglas thought that no evidence had been adduced

to show how the actual pebbles of clay had been formed.

He found it very hard to understand how two generations of rounded pebbles, one inside the other, could be formed in a plastic rock like a clay, by a movement that had caused fracture and shearing of the hard pebbles in the associated conglomerate. Further, in dealing with an exposure of so limited an extent

Quart. Journ. Geol. Soc. Vol. LXXXI, Pl. XXVIII.

Fig. 1.—Clay pebble-rock from Ancon (Ecuador). Natural size.



C. B. B. del.

Fig. 2.—Sea-cliff section of the clay pebble-bed (Ancon).



R. A. B photo.



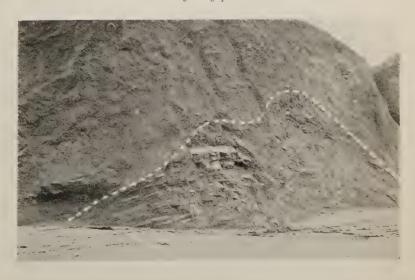
Quart. Journ. Geol. Soc. Vol. LXXXI, Pl. XXIX.

Fig. 1.—Clay pebble-bed overlain by unconverted and undisturbed clays and sandstones; sea-cliff section, Ancon.



R. A. B. photo.

Fig. 2.—Lenticle of stratified clays and sandstones in a mass of clay pebble-bed.



C. B. B. photo.



situated 130 miles west of the Andes, he considered that the suggestion of a thrusting of the Brazilian block over the Pacific

block was entirely unjustified.

Prof. W. W. Watts said that he was not convinced by the evidence brought forward that the conglomerates were produced by crushing. The structures exhibited in the diagrams were not very like those seen in, for instance, the crush-conglomerate of the Isle of Man, and he thought that the paper needed fortifying with photographs of exposures and with microscopic evidence. He pointed out the frequent association of breccias with orographic movement, and instanced the case of the Permian Breccias of Britain. He also referred to the occurrence of heavy screes and landslips, as in the Upper Rhine Valley at Flims and elsewhere, where their occurrence was associated with the outcrop of the upper ends of thrust-planes which gave rise to steepened slopes and the activity of all gravitational agencies of denudation.

Dr. T. O. Bosworth and Prof. O. T. Jones also spoke.

Mr. R. A. Baldry said, in reply, that the chief criticism levelled against the paper was that it did not bring forward convincing evidence to prove that the clay pebble-bed was formed by thrusting. He repeated the arguments put forward in the paper, amplifying them and supporting them by several lantern-slides.

First, he objected to the use of the word conglomerate in describing the bed. The word is associated so often with pebbles in a sandy matrix, that it might give a wrong impression of a

formation which is more than nine-tenths clay.

He recapitulated the evidence for its formation by thrusting:

(1) The absolute lack of stratification, and the large size of the boulders in a clay-matrix, precludes the possibility of ordinary sedimentary accumulation. Some boulders weigh several tons.

(2) The slickensiding polish on all the clay-pebbles and the high polish on the isolated quartz-pebbles indicate differential movement within the

bed

(3) The upper limit transgresses the bedding-planes of the superincumbent strata.

(4) The upper limit is always a thrust-plane, from which minor thrusts branch into the upper block.

(5) The most convincing evidence of all is the presence of a transitional stage where tearing-away of the sole of the upper block is visible, and one sees a cinematographic picture, so to speak, of the process of formation.

(6) No other hypothesis accounts for the large included blocks of stratified material; these may be 100 feet thick, and possibly several hundred feet long. The portions of these that are visible have the typical eye-shape that one associates with shearing movement.

The great thickness of the bed, compared with that of other known crush-conglomerates, is due to its formation from very soft strata. At Lobitos, in Northern Peru, belts of extreme brecciation are associated with normal faults. An instance is known of a fault with a throw of 2000 feet, in which the brecciazone is only a few feet wide where both sides are of hard strata; and yet, a short distance away, where the fault passes through clays, the belt is 100 yards across.

In reply to Mr. Lamplugh, he said that the material composing the bed is exactly similar to that of the sole of the overlying block. The included lenticles of stratified material, too, are identical with the rocks above. The foraminifera in the bed are like those of the sandstones in the stratified series. Where a sandstoneseam or a pebble-bed forms the sole of the upper block, one can see where portions have been pulled off it, and included in the claymatrix. The limestone, however, has not yet been found in the stratified series. It is only a thin bed, and might easily be faulted out in the cliff-section, and obscured by the Quaternary deposits inland. The foraminifera are like those of the sandstones above.

With regard to Prof. Illing's examples in Trinidad, the Ancon pebble-bed is confined to the zone of thrusting, and nowhere extends above it. There is no evidence of shoal conditions, except

much higher in the succession.

In reply to Dr. Douglas, Mr. Baldry said that the shearing of the pebbles occurred when the pebbly sandstones forming the base of the thrust-plane were breaking up. If the movement is reasonably slow, the maximum stress is limited by the rigidity of the matrix, and even a hard clay-pebble is protected, once it is surrounded by a cushion of softer clay.

The expression 'Brazilian block over the Pacific block' was meant to be directional only. It would have been clearer to have written 'from land to sea, or from the direction of the Brazilian block over the Pacific'. The impression of a hard resistant block on the south-east is derived from several years' investigations in Northern Peru and Ecuador, and not alone from the area described

in the paper.

In reply to Prof. Watts, Mr. Baldry opined that the difference in structure from the typical crush-conglomerates can be accounted for by the difference in the raw material. Photography is difficult, owing to the lack of contrast in the materials that form the bed, and it did not seem that the microscope could be of much use in this matter. Before the speaker went to Ecuador, he had suggested a possible mode of formation by submarine landslip near a large geofault at the edge of the continental shelf. This theory died a natural death, so soon as he saw the actual field-evidence, and the present theory took its place.

16. The Geology of the Rhobell Fawr District (Merioneth). By Alfred Kingsley Wells, D.Sc., F.G.S. (Read January 7th, 1925.)

[PLATES XXX-XXXII.]

CONTENTS.

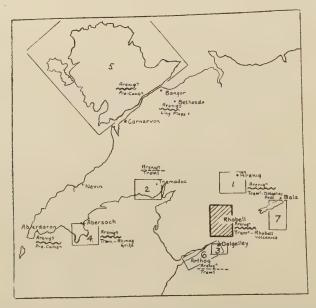
Ι	. Introduction	Page 463
11	. The Cambrian Succession.	
	(a) The Ffestiniog Beds.	100
	(b) The Dolgelley Beds.	
	(c) The Tremadoc Beds.	
III	. The Post-Tremadoc Interval	469
IV.	. The Rocks and Structure of Rhobell Fawr	471
	(a) General Account.	
	(b) The Relationship of the Volcanic Mass to Adjacent Strata.	
	(c) The Igneous Rocks.	
	(d) The Crystal Tuffs. (e) The Minor Intrusions.	
	(f) The Age of the Volcanic Series.	
V.	The Ordovician Succession	494
	(a) The Basement Group.	TUT
	(b) The Rhobell Fawr Outlier.	
VI.	The Llanvirn-Llandeilo Succession	503
	(a) Moel Offrwm.	
	(b) The Northern Part of the Area.	
VII.	The Main Volcanic Group	50 6-
	(a) The Pyroclastic Rocks.	
	(b) The Basic Lavas	
	i. Field Occurrence. ii. Petrography.	
	(c) The Basaltic Rocks.	
	(d) The Relation of the Basalt to the Spilites.	
VIII.	The Upper Acid Volcanic Group	517
IX.	The 'Bala Mudstones' and the Age of the Volcanic Rocks	518
X.	The Basic Intrusions	519
	(a) Field Relations.	
	(b) Petrology.	
	(c) The Dolerite-Aplites.	
***	(d) The Age of the Basic Intrusions.	× 0 =
		527
XII.	Summary and Conclusions	531

I. Introduction.

A STUDY of the existing geological maps of North Wales reveals at the south-eastern 'corner' of the Harlech Dome, inside the main Ordovician outerop, a group of hills which, although composed of igneous rocks, do not appear to form an integral part Q. J. G. S. No. 324.

of the 'ring of fire', from which they are separated by a narrow belt of Cambrian slates. The study of the geology of this group of hills, centred about Rhobell Fawr, and involving the investigation of the character of the rocks, their age, and relationship to those of the main Ordovician escarpment, has attracted several geologists before the present research was under-

Fig. 1.—Sketch-map showing the position of those parts of North Wales that have been recently re-surveyed.



[The relation of the lowest Ordovician to underlying rocks is indicated by a broken line in the case of disconformity and by a wavy line in the case of unconformity.]

- 1. Arenig & Moel Llyfnant. W. G. Fearnsides. 1905.
- 2. South-East Carnaryonshire. W. G. Fearnsides. 1910.
- 3. Mynydd Gader & Dolgelley. P. Lake & S. H. Reynolds. 1912.
- 4. St. Tudwal's Peninsula. T. C. Nicholas. 1915.
- 5. Anglesey. E. Greenly. 1919.
- 6. Arthog-Dolgelley. A. H. Cox & A. K. Wells. 1920.
- 7. Bala. G. L. Elles. 1921.

taken at the suggestion of Prof. A. H. Cox. The position of Rhobell Fawr in relation to other districts recently surveyed in North Wales is shown in the appended sketch-map (fig. 1). The district examined lies within the parish of Llanfachreth, and has been mapped on the 6-inch scale. The quarter-sheets covered by

the geological map illustrating this paper are Merioneth xx S.E.; xxvii S.E.; xxviii N.W.; xxviii S.W.; xxiii S.E.; xxxiii N.E.; xxxiii N.E.;

The stratigraphical succession ranges from low down in the Ffestiniog Beds to the Bala Mudstones. The former occur in the west, while the regional dip brings higher beds in towards the east. The central physiographic feature is the Rhobell mountain-mass, composed chiefly of volcanic material of early Arenig age. The mountain-mass comprises the central peak of Rhobell Fawr (2408 feet) and Moel Cors-y-Garnedd (1641 feet) on the south; Rhobell Ganol and Rhobell-y-Bîg on the north. In order to avoid misconception, the whole group of hills will be designated Rhobell. West of Rhobell the rocks include the major portion of the Ffestiniog Beds, together with many intrusions. East of it the Dolgelley and Tremadoc Beds are succeeded by a series of escarpments formed by the resistant Ordovician igneous rocks, the highest of which plunge steeply down under the soft Bala mudstones.

II. THE CAMBRIAN SUCCESSION.

(a) The Ffestiniog Beds.

In the well-known paper in which the lithological characters and fossil contents of the Lingula Flags are described by Thomas Belt, several references are made to the district including Rhobell Fawr, and the broad distribution of the Ffestiniog and Dolgelley Beds is outlined. The illustration accompanying the paper is a section passing almost due east-and-west through Moel Cors-y-Garnedd, which is shown as a vast intrusion uparching and breaking through the Lingula Flags, while the succession on the eastern side of the mountain is shown completely inverted. Apparently, Belt was deceived by the folding on that side of the mountain, as the succession is normal.

The Ffestiniog Beds occupy a broad belt of country in the western part of the area, and, even more so than in the district south of the Mawddach Estuary, give rise to unusually varied topography. Part of their outcrop forms open moorland clothed with scanty grass or heather, and often so marshy as to be impassable in wet weather. But these upland tracts are deeply dissected, in some cases to the extent of nearly 1000 feet, by straight V-shaped valleys occupied by strike-streams such as the Afon Wen and the Mawddach. These provide fine natural sections, although the valleys are in part well wooded. The dipsections in the bed of the Mawddach along the east-and-west part of its course, and along the northern edge of Moel Hafod

212

 $^{^{\}rm 1}$ 'On the $\it Lingula$ Flags of the Dolgelley District' Geol. Mag. 1867, p. 536.

Owen are among the finest in the country, as there is a steady eastward dip, and the exposures are almost continuous. The scarp of the Ffestiniog Beds is finely developed on Moel Cynwch (immediately west of the boundary of the map, Pl. XXXII), which is encircled by the Precipice Walk above the Mawddach Valley. The total thickness of the Ffestiniog Beds is difficult to estimate, as they are cut by strike-faults, the effects of which are not measurable; and, in addition, they include many intrusions which on Moel Cynwch must increase their real thickness by quite 50 per cent. On Foel Cae Poeth and Moel Hafod Owen trial-levels for slate have been opened in the ochreous-weathering flags near the centre of the group, which at certain levels are crowded with Lingulella, and yield occasional specimens of Hymenocaris vermicauda Salter. The highest part of the Ffestiniog Beds is found east of Rhobell Fawr, and again proves very fossiliferous.

The detailed petrographic study of the Upper Cambrian rocks is not yet completed, and little will be added to existing accounts at the present stage.\(^1\) It may be noted, however, that a regular banding, probably of climatic significance, is prominent throughout all but the top 50 feet or so of the Ffestiniog Beds. Towards the top of the series the banding becomes inconspicuous, with the failure of the sediment composing the 'ringers.' The general resemblance in lithology of these beds to certain other deposits, notably to the passage-beds between the London Clay and the Bagshot Beds in the London district, has recently occasioned comment.\(^2\) The Ffestiniog Beds of this district were deposited under neritic conditions, and consequently false bedding and ripplemarking are frequently seen. The latter is of the symmetrical

type formed under water by wave-action.

Although false bedding may occur at any level in the series, it is most conspicuous in the thickest ringer-bands, while the banded flags immediately above and below are usually parallel-bedded. The ringers are, as a rule, lenticular bands a foot or more thick, thinning out completely in a few yards. It seems reasonable to suppose that they were the accumulations of stormy periods when the supply of coarser detritus was temporarily augmented, and when current- and wave-action were at a maximum. It is perhaps noteworthy that the upper surfaces of the ringers are often crowded with specimens of Lingulella davisii.

(b) The Dolgelley Beds.

Although much softer, and hence more easily denuded than the underlying Ffestiniog Beds, the Dolgelley Beds are nevertheless

Notes on the Geology of Epping Forest' Proc. Geol. Assoc. vol. xxxiv (1923) p. 245.

¹ See papers by Prof. W. G. Fearnsides on Arenig and Tremadoc, Q. J. G. S. vol. lxi (1905) & vol. lxvi (1910) respectively.

far better exposed in this district than elsewhere in the southern half of their outcrop. The lithological and faunal divisions which have been proved to extend from Tremadoc to Arenig can be recognized in the Rhobell district also. The tough, fine-grained, grey-blue slates of the lower division are best exposed in the bed of the Mawddach west of Rhiw Felen. They are faintly laminated, though nearly uniform in composition. They are characterized by the occurrence of bands of pyrite in small cubes, and develop a rusty crust on weathering, rather than the iridescent film typical of the grey Tremadoc slates. Although they were doubtless deposited in deeper water than the underlying beds, the differences in lithology are due in part to the general levelling of the source of the sediment: slight false bedding is seen at levels quite high up in the Lower Dolgelley Beds. The change in lithology to a fine, even-grained, blue clay is accompanied by a notable change in the character of the fauna: the Lingulellas and worms of the Ffestiniog Beds give place to a more varied trilobite fauna. Complete specimens of but slightly distorted Parabolina spinulosa (Wahl) are the commonest form, most readily obtained from the slabs used for wall-building between Dol-Cyn-Afon and Rhiw Felen. Many of the bedding-planes from somewhat higher levels are crowded with Orusia lenticularis, accompanied by an occasional Parabolina and Ctenodonta sp. Small groups of immature trilobites are not uncommon.

The succeeding Upper Dolgelley Beds are likewise best exposed in the northern part of the district—in the bed of the Mawddach. They are moderately well exposed in the low ground between Rhobell and Moel Caer Defaid; while splendid sections are available for study in the several streams draining northwards off the moor between Rhobell-y-Big and Moel Gron. The streams have cut deep gashes in the slates, which in the upper parts of their courses are the soft, intensely black beds of the 'Black Band'. The lithology of these rocks indicates deposition in still deeper water. They are more earthy- and less silky-looking than the lower division, and over much of their outcrop are uncleaved, being laminated mudstones rather than slates, breaking with a curved fracture. In grain, colour, and high sulphide content (to which they owe their intense blackness) these beds resemble some of the clays now forming in the Black Sea, but differ from them in containing an abundant benthonic fauna at certain horizons. Although, on the whole, fossils are not abundant, at certain horizons, they have proved exceptionally plentiful. One of the best collecting-grounds is on the right bank of the second stream east of Rhobell-y-Bîg. Here a band a few inches thick consists chiefly of the fragmental remains of Sphærophthalmus alatus (Bœck). Head-shields, usually divested of free cheeks, are the most abundant fragments, while pygidia are scarce. Complete specimens of Peltura scarabæoides are not uncommon, though unattached cranidia are far more abundant. Large specimens of

Agnostus trisectus Salter are equally common. The complete fossil list for the Dolgelley Beds of the district consists of the following, many of which were recorded by Belt, and have been subsequently described and figured by Mr. Philip Lake in his monograph on the British Cambrian Trilobites:—

Beltella bucephala (Belt)
Olenus longispinus (Belt).
Parabolinella williamsoni (Belt).
Parabolina spinulosa (Wahl).
Sphærophthalmus alatus (Bœck).
Sphærophthalmus major Lake.
Dicellocephalus sp.
Peltura scarabæoides (Wahl).
Lingulella davisii.

Ctenodonta sp.
Ctenopyge bisulcata Phillips.
Ctenopyge directa Lake.
Ctenopyge expansa (Salter).
Ctenopyge falcifera Lake.
Ctenopyge teretifrons (Angelin).
Agnostus trisectus Salter.
Agnostus obtusus Belt.
Orusia lenticularis.

Unfortunately, the exact horizon of many of these forms cannot be determined, as the precise locality has seldom been recorded.

(c) The Tremadoc Beds.

Since the time of Ramsay's original survey, when the Tremadoc Beds were recognized in the neighbourhood of Allt Lwyd, little advance has been made in the study of these rocks in the district here described. This is partly accounted for by the paucity of good exposures, and partly by the comparative scarcity of fossils, without which it is difficult to establish the identity of the slates in isolated outcrops. The Tremadoc Beds form a broad band cropping out beneath the Basement Group of the Ordovician System, while the anticline east of Rhobell Fawr brings down the rocks again close up to the margin of the volcanic pile. Certain of the divisions established at Tremadoc and Arenig have been recognized, but the series seems less complete in the Rhobell district. In particular, the richly fossiliferous Shumardia Shales, Asaphellus Flags, and Angelina Beds have not been recognized, and the fossil lists are correspondingly meagre. In the mapping, the Dictyonema Band has proved a most useful datum-line, having yielded its characteristic fossil at many points. The Band is first well exposed in the extreme north on the right bank of the Afon Cwm Hesgen, where it forms the usual small scarp which here strikes towards, and is soon overstepped by, the Basement Group. the slates below, Belt obtained Niobe homfrayi Salter and Psilocephalus innotatus Salter, the two typical fossils of the Niobe Beds. For some distance to the south exposures are poor, on account of the covering of peat; but the Dictyonema Band can be traced almost continuously to the southern boundary of the map. The stream-cut bisecting the western slopes of Moel Caer Defaid provides a good section from the top of the Dolgelley Beds through the Niobe Beds (here cleaved into pencil-slates), and the Dictyonema Band, into the Bellerophon Beds above. The Dictyonemu Band strikes across the ridge following the outcrop of the Basement Beds above, while it and the underlying Niobe Beds have been quarried for slates between Rhobell and Moel Caer Defaid. In the lower and more cultivated ground in the southern half of the area exposures are very infrequent; but the gorge of the Wnion east of Rhaiadr-Wnion provides a dip-section in beds ranging through the Upper Dolgelley Beds and the Tremadocian into the Basement Group. There is no measurable discordance between the two last-named groups.

III. THE POST-TREMADOC INTERVAL.

Although in Europe no great earth-movements intervened between the close of the Cambrian and the opening of the Ordovician Period, a positive movement affected certain parts, bringing the higher Cambrian deposits within reach of denudation. The resulting unconformity is pronounced in North Wales, especially in Carnaryonshire and Anglesey, and a similar movement produced analogous results in Southern Scandinavia.

More than sixty years have elapsed since Ramsay first hinted at the unconformity below the Arenigian,² but a great part of the outcrops affected remain unmapped, and our knowledge of the relationship between the Tremadocian and the Arenigian is

correspondingly limited. (See map, fig. 1, p. 464.)

From the point where the Basement Beds of the Ordovician reach the sea to Arthog nothing is recorded as to the horizons on which they rest. In the Arthog-Dolgelley belt the Arenigian succeeds the Tremadocian with no demonstrable discordance of dip, but with a sudden and marked change in lithology. Although the actual junction is much obscured by strike-faulting, sills, and screes, it appears that the Tremadocian succession is as complete as at Arenig, and possibly as at Tremadoc.

Over a limited area around Dolgelley, the Basement Group, as shown below, rests directly on pre-Garth-Grit igneous rocks. No recent information is available concerning the Arans farther east; but a considerable thickness of Tremadoc slates above the Dictyonema Band is known to occur, succeeded unconformably by

igneous rocks of a peculiar type (p. 493).

In the Rhobell district the Basement Group rests in places upon the Rhobell Volcanic Group, and elsewhere upon the

Tremadocian as high as the Bellerophon Beds.

In the Arenig district the local base of the Ordovician transgresses in a few miles from the *Shumardia* Beds on to the Upper Dolgelley Beds. This transgression cannot continue indefinitely, however, as in the Tremadoc district the highest Cambrian, including the well-known *Angelina*-bearing slates, is more complete than in any other part of North Wales. The plane dividing these from the overlying Garth Grit shows small erosion-hollows,

¹ O. Holtedahl, 'Palæogeography & Diastrophism in the Atlantic-Arctic Region during Palæozoic Time' Amer. Journ. Sci. ser. 4, vol. xlix (1920) p. 1.

² A. Ramsay, Pres. Address, Q. J. G. S. vol. xix (1863) p. xxxix.

but the break is not pronounced. This is the more interesting, as in the Lleyn Peninsula the Arenigian rests in succession upon various members of the Cambrian System, down to the equivalents of the Rhinog Grits. Mr. T. C. Nicholas estimates that a minimum of 6000 feet of Cambrian rocks must have been eroded during the post-Tremadoc denudation.\(^1\) Still farther west the whole of the rest of the Cambrian is overstepped, and the Ordovician rests directly on pre-Cambrian. This relationship is paralleled in Anglesey, where Dr. E. Greenly's researches have proved the absence of this system, with the possible exception of the Careg-Onen and Baron Hill Beds, the systematic position of which has not yet been fully established. However, doubt as to the age of these beds does not alter the fact that some 5000 feet of Cambrian rocks present on the mainland have disappeared before reaching the Menai Straits—a distance of about 3 miles.2 This might conceivably be the result either of non-deposition or of subsequent erosion, but, with his special knowledge of the district, Dr. Greenly states that 'no doubt can remain that a considerable mass of Cambrian rocks must have maintained an aggregate thickness of 3000 or 4000 feet far over Anglesev' (op. cit. p. 402).

The above-mentioned facts prove the reality of the post-Tremadoc uplift, which was accompanied by folding and erosion. The dominant direction of these early folds seems to have been nearly due north and south, this being the direction of the minor folds in the Harlech Dome.³ South of the Cader Idris range, folds with the same trend, but affecting higher horizons, have been noted,⁴

and are probably posthumous along pre-Arenig axes.

Now, the Arenigian appears to rest upon a flat surface rising north-westwards, and in that direction, if not over much of North Wales, this must have been a land-surface. But the highest Tremadocian rocks bear little evidence of the uplift, so far as their lithology is concerned, and one must conclude that the succession is everywhere incomplete, though to how great an extent cannot as yet be tested.

The Rhobell district is unique, in that the break, the results of which are outlined above, was partly bridged by the advent

of igneous activity.

The relation of the products of this igneous episode to the underlying and overlying strata are considered in the subsequent paragraphs.

² 'The Geology of Anglesey' Mem. Geol. Surv. 1919, p. 401.

⁴ W. J. Pugh, 'Geology of the District around Corris & Aberllefenni' Q. J. G. S. vol. lxxix (1923) p. 531.

r 'The Geology of the St. Tudwal's Peninsula (Carnarvonshire) 'Q. J. G. S. vol. lxxi (1915) p. 139 & pl. xiii.

³ W. G. Fearnsides, 'Geology of North Wales' Geology in the Field, Geol. Assoc. 1910, p. 810.

IV. THE ROCKS AND STRUCTURE OF RHOBELL FAWR.

(a) General Account.

The earliest views recorded as to the character of Rhobell Fawr are those of Belt (1867), who, in the course of his pioneer work in this locality, regarded the mountain as a huge intrusion: he refers to it as the 'largest mass of diabase in Wales:' This was also the view held by Ramsay (1866) at the time of his original survey of the country,2 despite an earlier impression that the mountain was built of a succession of lava-flows ejected from some concealed vent. This first (and correct) view was temporarily abandoned, but the conclusion that the rocks are essentially of extrusive origin had been reached prior to the publication of the second edition of his memoir (1881). The only other publications dealing in any detail with the district are two papers by the late Prof. Grenville A. J. Cole & Sir Thomas Holland. In the earlier paper (1890) they give their conclusions as to the age and origin of the rocks of Rhobell Fawr,³ certain of which are described in the later contribution (1893).⁴ The present investigation has confirmed with certain modifications the more important results of these writers, and has made possible the correction of certain misconcèptions as to structure, the true interpretation of which vitally affects the whole problem. The detailed survey of the district has provided the observed facts, which alone make possible an adequate reasoned discussion of the many problems of Rhobell Fawr.

Admitting that the rocks are essentially extrusive, it remains to prove whether they mark the site of an actual cone, or whether they are the relics of outpourings from some more distant source. The evidence for this decision must lie in the character of the rocks themselves and in their relationship to surrounding and underlying strata.

(b) The Relationship of the Volcanic Mass to Adjacent Strata.

From a favourable view-point, such as Moel Hafod Owen or Moel Caer Defaid, Rhobell Fawr is seen as a dome-shaped rocky eminence rising abruptly from an undulating grass-covered tract occupied by Upper Cambrian slates. Its rocks are well exposed from foot to summit in innumerable crags which, however, by

4 'The Rocks of the Volcano of Rhobell Fawr' Geol. Mag. 1893, p. 337.

¹ On the Lingula Flags of the Dolgelley District: Pt. ii' Geol. Mag. 1867, p. 536.

² The Geology of North Wales' Mem. Geol. Surv. 1st ed. (1866) p. 43. ³ Structure & Stratigraphical Relations of Rhobell Fawr' Geol. Mag. 1890, p. 447.

reason of their lack of orderly arrangement fail to convey any hint of the structure of the mountain: there is no interbedding of harder and softer strata, such as occurs everywhere along the main Ordovician escarpment, suggesting that the rocks, whatever their nature, constitute one stratigraphical unit.

The approximate boundary of the igneous mass is not difficult

to follow, but actual junctions are rarely exposed.

On the west the junction was thought by Ramsay to be faulted. In the broad valley north of the col connecting Moel-y-Llan and Cerniau there is no direct evidence of faulting, as the Ffestiniog Beds, well exposed on the smooth slopes of Moel Hafod Owen, are separated from the igneous rocks forming the rugged crags on the opposite flank of Rhobell Fawr by a belt of alluvium and cultivated fields. South of Cerniau the boundary, as shown on the original 1-inch map, corresponds with a series of intrusive junctions between the minor intrusions in the Ffestiniog Beds and the slate-bands themselves. The latter are very steeply inclined (70 to 90°), and doubtless differential movement has taken place along the contacts, but there does not seem to be one great displacement.

In the northern part of the Rhobell area the sheet like form of the northward-thinning igneous mass is self-evident: each salient in the outcrop corresponds with a spur, and each re-entrant with a hollow, while the former northward and eastward extension of the sheet is proved by the occurrence of numerous outliers in these directions. Those lying north-east of the main outcrop rest on abundantly fossiliferous *Peltura* Beds, while those on the east are separated by narrow glaciated depressions in which slates belonging to higher horizons are seen. The most prominent of the outliers are the picturesque peak of Craig-y-Dinas, severed by the down-cutting of the Mawddach, and the tor-like eminence of

Moel Grôn.

At one locality only round the margin of the Rhobell mass are there clear extensive sections exposing the base of the sheet. These occur in the north-west, where the rejuvenation of the Geirw has allowed the stream to rip a gorge through the volcanic rocks into the slates beneath. Where the latter first emerge, the junction is clearly vertical, probably faulted, though at least one sill extends from the andesite on the right bank to the Peltura Beds on the opposite side of the gorge. Farther down stream the andesites are clearly resting as a nearly horizontal sheet upon the slates, which are penetrated by a number of dykes and small bosses of andesite, one of the latter forming a meander-core. The sheet rapidly transgresses from Black Band (Upper Dolgelley Beds with *Peltura scarabæoides*) to Lower Dolgelley Beds with Parabolina spinulosa, and a short distance farther north-west must once have extended over the eastward-dipping Ffestiniog Beds.

Along much of the eastern margin of the Rhobell mass the

slates can be followed up to within a few feet of the contact. Both Dolgellev and Tremadoc Beds are well exposed in artificial sections along the track skirting the foot of the mountain and in numerous dip-sections cut by streams flowing eastwards off the mountain. Apparent inversions hereabouts, though possibly due to overturning of folds against the igneous massif, are more probably the result of minor faulting. Judging from the not infrequent occurrence of Dictyonema in the track-side exposures, the slates actually in contact with the igneous rocks must be at least as high as the Bellerophon Beds in the Tremadocian. Confirmation is afforded by the slates thrown out from the triallevels at Craig-fâch, these having the iridescent film and chalky white markings characteristic of the lower parts of the Tremadoc Series. The slates are much crushed and disturbed, which renders fossil-collecting from them rather a disheartening task; but they have yielded Lingula lepis and fragments of a broad form of Asaphellus homfrayi, while from the Dolgellev Beds below Peltura scarabæoides and Dicellocephalus sp. have been obtained, in addition to Lingulella davisii, 'Olenus', (Sphærophthalmus) alutus, and a 'Conocoryphe' recorded by the Geological Survey. Above the trial-levels a brown-weathering andesite, locally flowbrecciated, rests upon the slate, the contact inclining gently into the mountain; though not far distant it is vertical, and presumably faulted.

Southward from Craig-fach the boundary is very irregular, part of the line on Ramsay's map being the base of a gabbroid doleritesill, much younger than the Rhobell rocks, intrusive into the Dolgelley Beds. Orusia lenticularis and a number of small Linguiellæ were collected from the spilosite above the sill, while the Peltura Beds occupy the hollow between the sill and the true margin of the Rhobell mass.

From a point below the summit of Moel Cors-y-Garnedd the boundary swings south-eastwards for about a mile. This is believed to be an intrusive junction, because

(1) it pays no heed to the strike of the slates, which

(2) are toughened and bleached, breaking into irregular lenticles under the hammer;

(3) fragments of slate are incorporated in the marginal parts of the andesite, and stand out from its weathered surface as resistant knots;

(4) at one point an irregular plunging contact is seen, dipping steeply towards the slates, which latter are firmly cemented to the igneous rock.

The igneous rocks in contact with the slates are andesitic, distinctly brecciated on weathered surfaces, and at the first glance were thought to be agglomeratic. A pseudo-stratified appearance, consequent upon the development of nearly horizontal closely-spaced joints, increases their resemblance to extrusive rocks. There is little doubt, however, that the rocks are definitely intrusive, and it may be noted that similar occurrences in Mull have been

interpreted as due to vent intrusions 'breaking up to yield vent-

agglomerate.'1

Additional evidence of intrusion is obtained in the neighbour-hood of Bryn Brâs and Ystum Gwadnaeth, between which places the boundary reaches its maximum complexity. The distribution of the outcrops and the form of the ground suggest that the igneous rocks have been in part removed by denudation, exposing irregular patches of the underlying rocks. But, in places, skins of slate are seen adhering to the tops of small bosses of andesite, which occasionally contain lenticular inclusions of slate, sometimes of considerable size. Near Maes Gwyn a diorite-porphyry containing prominent phenocrysts of hornblende has converted the Upper Dolgelley Beds with which it is in contact into typical knotenschiefer, while farther north it fingers out into the slates in a manner suggestive of half of a cedar-tree laccolith.

At Ystum Gwadnaeth the Cambrian Slates disappear, and the massive ashes of the Basement Group spread far up the slopes of Moel Cors-y-Garnedd, being faulted against the Rhobell rocks, which are here purple and green andesites. Farther west a thick

mantle of drift obscures the solid geology.

In brief, the nature of the junction between the igneous rocks of Rhobell Fawr and the contiguous strata varies in character in different parts of its course: it is faulted on the south, and possibly also on the west, where, however, the line is obscured; in the south-east it is intrusive; in the north the igneous rocks rest upon an irregular surface of slate belonging to different levels in the Upper Cambrian, ranging from the Parabolina Beds in the Lower Dolgelley Group up to the Bellerophon Beds in the Tremadocian.

(c) The Igneous Rocks.

The facts set forth above are consistent with the hypothesis that the Rhobell mass is the deeply dissected ruin of an actual volcanic cone, the main crater of which probably lay some short distance away to the west or south-west of the mountain. reconstruction of various stages in the development of the present structure of the mountain has been attempted (fig. 6, p. 492), and is discussed later. West of the relic of the volcanic pile many intrusions occur, which, although mainly sill-like in habit, may have functioned as dykes, and served as feeders of the volcano. The most significant fact in this connexion is that the geographical distribution of the intrusions coincides with, but is somewhat less extensive than, the present north-and-south tract of volcanic rocks. When examining these intrusions, I found it difficult to delimit the eastern boundary of the belt within which they occur. The discovery of one thin (and usually discontinuous) slate-band after another, in a tract consisting essentially of igneous rock, pushed

¹ 'Tertiary & Post-Tertiary Geology of Mull' Mem. Geol. Surv. 1924, p. 158.

the boundary continuously farther east, well into what was formerly mapped as the volcanic mass. The easternmost slate-band lies on the eastern flank of Cerniau, but beyond it there is little change in the lithology of the rocks across Bwlch Goriwared to within a short distance of the summit of Moel Cors-v-Garnedd, and well up on the south-eastern slopes of Rhobell Fawr. The rocks are not absolutely uniform over this area, they differ slightly in texture, in the proportions of their components, and probably also in mode of origin, but these differences are illdefined. Although exposures are practically continuous on the extensive joint-surfaces, which, in this part of the mountain, give a terraced appearance to the crags, lines that would be possible to map are conspicuously absent. Occasionally a faint banding can be discerned, yet this is no more pronounced than in several of the proved sills. Sometimes two slightly different rock-types come into contact with sharp junctions, but the line is invariably lost in a few yards, and as a rule there is a transition from one type to another. The few exceptions, however, are significant. The common type in this tract is a felspathic grey-weathering rock, which, in one place, at least, abuts sharply against a finer-grained rock with prominent phyric 1 hornblende-crystals. Xenoliths of the latter rock, some clearly defined, others less definitely outlined, are embedded in the former, clearly proving it to be intrusive into the hornblendic rock. These rocks are characterized by

(1) a petrographic type almost identical with some of the sills in the west;

(2) uniform lithic features over a considerable area;

(3) lack of vesicularity;

(4) vertical intrusive contacts;

(5) inclusion of accidental xenoliths of sedimentary and igneous rocks;

(6) a chilled marginal phase traversed by contraction-joints; and

(7) occasional 'aplite'-veins.

Thus there can be no doubt that much of the felspathic rock

extending eastwards from Cerniau is intrusive.

Rocks which appear agglomeratic, or at least brecciated, on weathered surfaces, can be found with little difficulty almost anywhere within the boundary of the volcanic mass. Close inspection proves some to be flow-breccias, while intrusion-breccias and crush-breccias are well illustrated in the intrusions in the Ffestiniog Beds. The crush-breccias can resemble agglomerates somewhat closely; but, as a rule, a transition is traceable from a rock built of abraded and rounded fragments set in a matrix of crushed rock, through an intermediate stage in which the amount of rounding is slight, to rock normal in all respects, save for the presence of numerous irregularly arranged joints cutting up the rock ipto angular fragments. With regard to 'auto-brecciation', this structure has been shown to be an attribute of submarine

¹ Phyric=porphyritic; see H. S. Washington, 'Petrology of the Hawaiian Islands' Amer. Journ. Sci. ser. 5, vol. v (1923) p. 473.

lavas.1 The rocks of the Lake District and of Rhobell Fawr are similar in many respects; but, from considerations discussed later (p. 479), it is believed that those of the latter were ejected from a subaërial cone. Thus auto-breccias may be ruled out, but the occurrence of block-lavas ('aa' type) is to be expected, as the magma was essentially andesitic. Such lavas are well exposed south of Moel Cors-y-Garnedd, near the summit. A marked agglomeratic structure develops on weathered surfaces, the blocks being large, angular to subangular, and closely packed. scanty matrix is rough and scoriaceous in appearance. Examination of both blocks and matrix proves them to be andesitic, with only slight differences in microscopic texture. In certain cases the included blocks prove less resistant to weathering than the matrix of rough slaggy lava in which they are embedded. This type is seen to advantage on the prominent crag (2313 feet) south of the summit of Rhobell Fawr, and again immediately below the explosion-tuffs west of Moel Cors-y-Garnedd summit. In both cases the freshly fractured surface shows little or nothing of the brecciation which weathering emphasizes so strikingly. A modification of the same structure is seen in rocks the surfaces of which are delicately laced over with frothy slag.

But, although some of the so-called 'agglomerates' prove to be lavas, true explosion-tuffs of various grades occur at more than one level, and include some of the most conspicuous rocks of the series. The main outcrops are marked on the map (Pl. XXXII). By far the most spectacular outcrops occur on Eglwys Rhobell. north and north-west of the summit of Rhobell Fawr. Here they form dark rugged crags rising conspicuously above the general level of the ground, while the rocks building them provide striking evidence of the violence of the eruptions during Rhobell's active period. That they are true explosion-tuffs, and that their components were dropped straight into their present position, is as clear as if one had actually observed the eruptions. Indeed, standing among these grey crags, one finds it difficult to realize that the events of which they are the tangible record took place at the opening of the Ordovician Period. Whole cliffs of these coarse tuffs are devoid of any trace of stratification, but occasionally, owing to slight differences in the size of the components, or vague colour-changes, a rude bedding can be discerned.

The materials composing these rocks range through the complete series, from the finest dust to angular blocks measuring 3 or 4 feet in maximum diameter. A distinctive type occurring south of the summit, and within a few yards of the Basement Group, consists of closely-packed 'drops' of lava of the size of peas. In other parts the constituents are lapilli of the size of walnuts, or bombs a few inches in diameter, the monotony being relieved

¹ J. F. N. Green, 'The Vulcanicity of the Lake District' Proc. Geol. Assoc. vol. xxx (1919) pp. 157-61.

by occasional abnormally large volcanic blocks. As a rule, the various components are thoroughly mixed, with no trace of grading according to size. These larger components are embedded in a matrix of finer volcanic 'sand' and dust, the proportion of which varies considerably. It occurs in dumps in the agglomerates containing only a smattering of large fragments, while a few yards away the latter may predominate, the matrix being reduced to a minimum. In the finer ash, as well as in the coarser tuffs, a plentiful sprinkling of crystals or fragments of hornblende and augite can usually be seen.

It is significant that in some cases the agglomerates occur within circumscribed areas, and that vertical junctions with contiguous rocks have been observed. In such cases the outcrops undoubtedly mark the position of the vents of parasitic cones: such is the small rounded outcrop on the northern flank of Cerniau. In other cases, the coarse tuffs are definitely interstratified bands at different levels on the mountain, separated one from the other by considerable thicknesses of ash, lava, and vent intrusions. Far from being the basal tuffs of a volcanic series, some bands are found within a few yards of the summit. It should be noted that the discontinuity of the outcrops is frequently the result of invasion by later (but probably pre-consolidation) intrusions. The relation of the latter to the agglomerates is clearly seen on Eglwys Rhobell, where they take the form of approximately east-and-west dykes measuring up to 10 feet in thickness.

Petrographic features of the coarser tuffs .- The singular monotony in the composition of the fragments in the coarse tuffs is an outstanding feature. Superficial examination of considerable tracts fails to reveal more than two or three different kinds of rock-fragment, which are, moreover, all igneous, matching very closely other massive rocks now exposed on the mountain. There seems to be an almost complete absence of shale, grit, or other sedimentary rocks, which must underlie the igneous mass at no very considerable depth. This indicates that the tuffs were formed chiefly from the disruption of ascending lava-columns, together with the products of earlier eruptions; also that the point of origin of the explosions was not deep-seated. The presence of rocks already solid at the time of their incorporation in the tuffs is proved by an occasional angular block of andesite traversed by quartz-veins which do not penetrate the matrix. Various kinds of andesitic rock are represented, varying in texture, as do the lavas themselves, and in the number and size of the phenocrysts of dark minerals.

Probably the commonest type is a grey smooth-weathering rock with prominent, evenly-spaced hornblendes and augites rather less than a quarter of an inch in diameter. The parent-rock of these fragments has a wide distribution on Rhobell Fawr, and is chiefly intrusive—it forms the dykes mentioned above. Fragments of rock indistinguishable from the diorite-

porphyry intrusions in the Ffestiniog Beds (described later, p. 481) are equally plentiful. Pale-weathering felspathic andesite, in which the chief mineral is plagioclase in small tabular crystals, showing a sharply-defined flow-structure, is also well represented. These perfectly formed crystals are just large enough for their crystallographic features to be determined.

The freshly fractured rock, although more uniform in appearance than when weathered, is quite distinctive: it is dark, with purple and green blotches, in which nests of epidote-crystals are always conspicuous. Many

of the included fragments are so epidotized as to be yellowish-green.

(d) The Crystal Tuffs.

At the localities named above where the coarse tuffs are specially well developed, interesting crystal tuffs occur showing prominent 'phenocrysts' of plagioclase, augite, and hornblende. Rhobell Fawr is best known on account of these almost unique rocks. They are among the few rocks in the series which are definitely, though only feebly, stratified, as, for example, on the peak of Rhobell-y-Big. The crystals range in size up to 1×0.5 inch, and occasionally occur in knots recalling the olivine-nodules of some basalts. Unlike the coloured minerals in the majority of the rocks of this district, they are remarkably well preserved, even on exposed surfaces, the black lustrous crystals standing out prominently from the grey ashy matrix. With regard to the source of the crystals, it seems unnecessary to draw upon an amphibolite, or, indeed, upon any rock of earlier formation lying beneath the cone. Their high degree of idiomorphism is inconsistent with a plutonic source, as is their frequent occurrence in fragments of fine-grained rock. Both hornblende and augite occur as phenocrysts in the lavas, and in the associated intrusive and pyroclastic rocks. In all three they sometimes attain to quite as large a size as in the rocks under discussion. Hornblende in particular is ubiquitous, and is the characteristic dark mineral of the suite. The crystals were undoubtedly derived from a lava-column rising from a magma reservoir, in which fractional crystallization had resulted in the settling of a crop of crystals of early-formed minerals. Such crystal tuffs are not common in British volcanic rocks, but similar accumulations are well known elsewhere—the showers of leucite- and augite-crystals from Vesuvius may be cited as examples. Judging from the published descriptions, the crystal tuffs of Rhobell Fawr are almost exactly paralleled at Bail Hill, Sanguhar, near Girvan, in a volcanic series probably of not very different age. Sir Jethro Teall's descriptions 1 of these tuffs might well have been written concerning the Rhobell rocks.

In addition to the agglomerates and crystal tuffs, pyroclastic rocks of finer grain occur in abundance, but have proved unsatisfactory subjects of study. Most of the volcanic dust seems to have been carried beyond the limits of the present relic, most

¹ 'The Silurian Rocks of Britain: Vol. i—Scotland' Mem. Geol. Surv. 1899, p. 305.

of the material preserved belonging to the grade somewhat inappropriately termed 'volcanic sand'. This material, which is piled up in considerable quantities, consists chiefly of crystals and fragments of plagioclase. Its true character is betrayed by an occasional sprinkling of bombs or larger fragments of andesitic rock, and by still rarer traces of bedding. The contrast in this respect with the ashes of the higher volcanic series is very striking. The latter also include felspar-crystal tuffs, of somewhat coarser grain, quite well stratified and graded, which points to deposition under water. The Rhobell volcano, on the other hand, was probably subaërial. The lack of sorting and of bedding and the irregular disposition of the beds indicate deposition on the flanks of a subaërial cone. On general stratigraphical grounds this is scarcely open to doubt: the eruptions were preceded by a period of denudation, and were followed (after an interval, during which there was further erosion) by the deposition of sediments formed under shallow-water conditions. In addition, there is no trace of pillow-structure (which characterizes the higher volcanic series), and there is no trace of intercalated normal marine sediment. It has been stated in previous accounts that there are interlacings of slate on Rhobell Fawr; but there is definitely no slate or any other kind of sedimentary rock between the base of the volcanic series and the Arenigian sediments above.

Microscopic Features of the Extrusive Rocks.

(i) The Lavas.

Except in so far as they provide material for the study of the alteration of the minerals commonly found in andesites, the lavas of the Rhobell Volcanic Group can lay no claim to special interest. In many of the slides alteration is so complete as to mask entirely the original characters of the rock. Many of the pseudomorphs after the original coloured minerals have not retained their shape sufficiently well for the certain identification of the replaced mineral, but in other cases this can be identified as hornblende or as augite, while pseudomorphs after olivine, distorted by subsequent squeezing, occur in a lava below the Basement Group on Moel Cors y-Garnedd The original composition of the felspar is a matter for surmise. It is now albitized plagioclase occurring in two generations, the earlier in highly idiomorphic, strongly zoned crystals; while the second generation varies from mere microlites to rather stout, stumpy laths. In some of the more basic members of the series, which are almost black in hand-specimens, the felspars of both generations are outlined with magnetite dust, rendering the texture of the rocks remarkably clear. It is clearly impossible to name these rocks with the desired precision. Prof. H. S. Washington has systematized the nomenclature of basalts and andesites, and has defined the distinction between them.2 So far as the Rhobell lavas are concerned, it seems reasonable to call them hornblende- and augite-andesites-using the terms in a wide non-committal sense. The possibility of some of them having been

¹ See A. C. Ramsay, 'Geology of North Wales' Mem. Geol. Surv. 2nd ed. (1881) p. 58.

² 'Petrology of the Hawaiian Islands: pt. i' Amer. Journ. Sci. ser. 5, vol. v (1923) p. 468.

Q. J. G. S. No. 324

basalts originally is recognized; but, in the present condition of these rocks,

Washington's criteria cannot be applied.

The paler rocks of Cerniau, which, as shown above, are in part at least intrusive, and those that occur above the agglomerates on Eglwys Rhobell, are certainly more felspathic than those just described; even in the most acid examples, however, chemical analysis proves but a very small percentage of potash, and the felspar must be almost entirely plagioclase. Apart from the texture, which is sometimes trachytic, there is little justification for recording them as trachytic andesites.\(^1\) They are the most acid differentiates of a magma essentially andesitic, but even they depart but little from the average type, differing rather in the proportions than in the kinds of minerals that they contain. Reference may also be made to the suggestion in an earlier paper that these rocks may originally have contained nepheline.2 Fresh nepheline could not be expected, and it is doubtful whether its decomposition-products could be identified in rocks of such great age and so highly altered. But, on general grounds, it seems impossible that felspathoids could have ever been present. When the coloured minerals are preserved, they are found to be normal hornblende and augite, and not the strongly coloured varieties which usually accompany nepheline. The analysis (p. 484) is that of a normal member of the calcic suite—it has no affinity with the alkalirocks.

(ii) The Tuffs.

As the crystal tuffs pass gradually into the coarser types including the agglomerates, both are here dealt with together. The majority fall into the group of lithic tuffs (Pirsson); they are composed of angular fragments of andesitic rocks, some of which were originally glassy (though now completely devitrified) containing minute chlorite-filled vesicles in great numbers. The ground-mass of most of the other fragments is microlitic, following the general rule in being rather less crystalline than the actual lavas. The large crystals of plagioclase, hornblende, and augite occur in varying proportions, the first-named only being present in all slides examined. The zoned plagioclase-crystals are considerably smaller and less well-preserved than the coloured minerals.

The augite, which is not always present, is the normal type found in the less basic lavas -pale green to colourless in thin section. An unexpected feature is the frequency with which crystals are faintly zoned; they show a distinct hour-glass structure (seen only between crossed nicols), while simple

and lamellar twinning are not uncommon.

Two varieties of hornblende occur: by far the commoner is the ordinary brown kind, not strongly coloured, and sometimes twinned on (100). In addition, occasional crystals of basaltic hornblende occur. The common hornblende has been altered in a peculiar manner: in many slides there are more 'ghost-pseudomorphs' after hornblende than crystals of the mineral itself. The 'ghosts', consisting chiefly of tremolite, are scarcely (if at all) visible in ordinary light. The only indication of their presence is a vague polygonal outline enclosing an area almost identical with the grey irresolvable ground-mass. Between crossed nicols, however, the enclosed shape yields the characteristic interference-tints of hornblende. The outline of the ghost is slightly accentuated by a fine separation of magnetite-dust. In a few cases it encloses a core of clear unaltered hornblende, while both core and matrix yield the same interference-colours and extinguish simultaneously.

The only other minerals identified in the tuffs are epidote, zoisite, chlorite, the usual iron-ores, and many sharply-pointed small crystals of tremolite.

¹ See G. A. J. Cole, 'Rocks of the Volcano of Rhobell Fawr' Geol. Mag. 1893, p. 340. 3 Id ibid. p. 339.

(e) The Minor Intrusions.

The rocks defined by Cole & Holland as 'trachytic intrusive andesites',1 occur as intrusions occupying part of a broad belt of country lying west of Rhobell, chiefly in the Ffestiniog Beds. In the magnificent succession of the latter on Moel Hafod Owen, intrusions are inconspicuous, especially in the north, but increase in importance on the south. They are common on Foel Cae Poeth, and attain their maximum development on Moel-y-Llan, Cerniau, and Mynydd t'Isaf. Farther south the rocks sink beneath the thick drift which fills the Llanfachreth valley, and exposures are few. South of the valley, however, intrusions of the same type appear in force in the higher parts of Moel Cynwch, above the Precipice Walk, and continue along the same line of strike to the outskirts of Dolgelley. North of the volcanic mass in the black Dolgelley Beds there are no intrusions of this series, while east of the Rhobell mass there is one. Despite their abundance in the Ffestiniog Beds, not one occurs in the Tremadocian, nor above the base of the Ordovician -a fact of importance in considering their age.

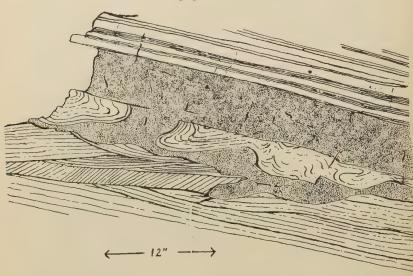
Although the greater part of the tract in which the intrusions occur is covered with rough pasture, peat, or heather, exposures, if discontinuous, are good, and many actual junctions seen render it possible in most cases to demonstrate the general sill-like habit of the intrusions, especially of the smaller ones. The fact that the country-rock is well bedded accounts for the attitude of the intrusions: the rapid alternations of flags with siliceous 'ringers' have provided a great number of planes of easy passage for the advancing magma, while the more homogeneous Dolgelley and Tremadoc Beds have proved far less penetrable. Near the western margin of the map (Pl. XXXII) the sills dip more or less concordantly with the bedding of the Ffestiniog Beds. As the edge of the volcanic mass is approached the dip increases, until both slates and sills are nearly vertical. In fact, a reversed dip at an equally steep angle is occasionally to be observed, as in Bwlch Gwyn. Although most of the intrusions are concordant, a certain amount of discordance is common, and occasionally the magma has advanced along planes inclined as much as 45° to the bedding. No true dykes occur among the sills, but the larger bodies are much less regular in behaviour and shape, and send out short veins into the surrounding slates. A noteworthy feature is the frequency with which the intrusions bifurcate. The thickness of the slate separating one sill from another decreases from west to east, so that the intrusions become crowded together as the margin of the volcanic mass is approached.

As might be expected in a series of almost vertical strata with interbedded sills, differential movement has caused much faulting—some transcurrent (approximately north-west and south-east) and

^{&#}x27; 'Rocks of the Volcano of Rhobell Fawr' Geol. Mag. 1893, p. 337.

some overthrusting on a minor scale. This, coupled with the overgrown nature of the ground, makes it impossible to follow any sill for more than a limited distance. When no movement has taken place along the junctions, the sill-rock, however thin, has converted the shale into a tough, white-weathering 'hornfels', still retaining a trace of the original bedding. A well-developed flow-banding has sometimes been produced parallel to the junction, in which case there is no sharp divisional line between intrusion and country-rock. More rarely, a contorted flow-banding has developed near the margins. On Moel-y-Llan and Mynydd-t'Isaf a sill, in the

Fig. 2.—Sill of microdiorite in a false-hedded 'ringer', Mynydd t'Isaf.



former case only 6 inches thick, has invaded a current-bedded 'ringer', and through the onward flow of the magma has contorted the included softened xenoliths (fig. 2). Several cases of intrusion-breccias have been observed, especially on Cerniau, where the xenoliths are somewhat rounded, and show a fluxional arrangement parallel to the margin of the sill. In considering the age of the intrusions evidence may be adduced from the petrographical characters of the rocks and from their stratigraphical position.

Petrography.—The intrusions present at first sight a singular and somewhat deceptive uniformity of appearance in the field, resulting from alteration of a series of allied rock-types into the same secondary minerals. In most cases, no name other than 'greenstone' can be applied before submission of the rock to microscopic examination. The freshly fractured surface is of a uniform

blue-grey, and is practically featureless. The partly weathered rock, however, shows an abundance of small felspar-phenocrysts seldom exceeding a quarter of an inch in length, together with fewer though larger pseudomorphs after hornblende, which on Cerniau and Moel Cynwch occasionally approach half an inch in diameter. They are very easily removed by weathering, thus causing the rock to be uniformly dotted over with polygonal cavities. This 'pseudovesicularity' is one of the most characteristic features of the rocks. The pseudomorphs, or in their absence the polygonal cavities, bear interesting testimony to the deformation suffered by the rocks: in certain cases, although still polygonal, they are obviously distorted and flattened, while in others they are reduced to short dark lines. Long exposure to the weather gives to the rocks a thick, almost white crust, which emphasizes and perhaps exaggerates their felspathic nature.

An unexpected though constant feature is the presence of considerable numbers of cubes of pyrites, sometimes exceeding an inch in diameter. Most of these are elongated along one or two cubic axes, but there is no constant relationship between the direction of elongation and the cleavage-strike of the district. The cubes are thinly filmed over with limonite, and may be collected in large numbers from scree-material below the sills, especially on the narrow ridge at the head of Bwlch Gwyn. The enormous amount of pyrites in the rocks, their generally completely altered condition, and in particular the prevalence of epidotization, may plausibly be ascribed to solfataric action, during the phase of waning activity.

Although so much altered, and hence offering little attraction to the petrographer, these rocks have one other claim to interest: they are intimately associated with and are cut by quartz-lodes which have been prospected for precious metals on the southern slopes of Moel Hafod Owen, on the western side of Moel-y-Llan and of Cerniau. In no case has the search resulted in the discovery of mineral rich enough to repay the cost of mining.

Under the microscope the advanced stage of decomposition is only too apparent, and it was only after a series of slides had been cut that the affinities of many of the rocks became clear.

Type 1 (fig. 3, p. 486). The rock is strikingly phyric, the fluxionally arranged felspars and large (though less numerous) hornblendes being conspicuous. Quartz-phenocrysts occur as sporadic bipyramidal crystals, often enclosing small idiomorphic felspars in poikilitic fashion. Both plagioclases and hornblendepseudomorphs show an equal perfection of form. The plagioclase is twinned on the albite and pericline laws, while occasionally there are good cruciform twins. Although now approaching pure albite in composition, the large amount of enclosed lime-bearing compounds, chiefly epidote and calcite, proves them to have originally been of more basic composition. Others, equally well formed, are less altered, being merely dusted through with paragonite and epidote, and were originally less basic.

The hornblende-pseudomorphs are variable in size, and consist of chlorite, iron-oxides, and epidote in varying proportions.

The phenocrysts are embedded in a microcrystalline ground-mass of felspar, chlorite, and quartz, which is of too fine a grain for any reliable estimate of their proportions to be made.

The rock is dacitic in composition, differing from the andesites

of Rhobell in the presence of two generations of quartz.

The dacite from Cerniau has been analysed by Dr. H. F. Harwood, the details being tabulated below, together with the average analysis of ten dacites, and that of an andesite which agrees closely with our rock :-

1 TOOLES			
	I.	II.	III.
Silica	64.30	65.76	64.22
Alumina	16.82	17.62	16:36
Ferric oxide	1.99	2.54	2.93
Ferrous oxide	2.25	1.99	2.50
Magnesia	1.62	1.21	1.94
Lime	4.96	4.02	5.85
Soda	5.26	3.82	3.96
Potash	0.16	2.01	0.73
Water above 110° C	1.82	0.52	0.84
Water below 110° C	0.10		
Carbon dioxide	0.02		**,
Titanium dioxide	0.35	0.25	0.21
Zirconia	trace		-
Phosphoric oxide	0.23		
Chlorine	trace	aproxime.	trace
Sulphur	0.03	-	
Manganous oxide	0.14		
Strontia	none		
Barium oxide	none		_
Lithia	none	-	
	100.35		
less 0 for S	8 0.01		
Total	100.34		

- I. Dacite, Cerniau, Llanfachreth (Merioneth).
- II. Average of ten analyses of dacites, from H. S. Washington's. 'Chemical Analyses of Igneous Rocks' U.S. Geol. Surv. Prof. Paper No. 14, 1903.
- III. Hornblende-andesite, Mexico, quoted from the same work, p. 245.

The most striking features of the new analysis are the high percentage of soda and the very low potash for the silica present. This abnormality must be regarded as a characteristic of the magma underlying this district, as the same feature has been noticed in the basalt and spilites of the higher (Llandeilo) volcanic series.

The norm of the rock is as under:-

]	Per cent.
Quartz	18.6
Orthoclase	0.9
Albite	46.8
Anorthite	20.3
Dismaids [wollastonite	1.1
Diopside { wollastonite	1.0
Hypersthene $\left\{ \begin{array}{ll} \text{MgO, SiO}_2 & \dots \\ \text{(Fe, Mn) O, SiO}_2 & \end{array} \right.$	3.1
	2.0
Apatite	0.5
Ilmenite	0.7
Magnetite	2.9
Calcite	0.1
Pyrite	0.1
Water	1.9
	100.0
	-

If the small amount of orthoclase is calculated with the albite, the plagioclase has the composition of oligoclase-andesine, or approximately $Ab_{70}An_{30}$.

Type 2.—A less common type, differing only in minor particulars from Type 1, contains less first-generation quartz, sometimes furnished with a narrow outgrowth penetrating the ground-mass. The plagioclase shows to advantage the pronounced zonary banding often regarded as characteristic of andesites, the core of the zoned crystals consisting chiefly of coarsely crystalline epidote. Complete albitization has, however, obliterated original differences in composition between successive zones. The coloured minerals, which are again completely pseudomorphed, have less frequently retained their shape, but undoubted basal sections of hornblende are not uncommon, while ragged chlorite-pseudomorphs after biotite still retaining traces of the original cleavage occur in places. Although phenocrysts of quartz are not abundant, there appears to be more of this mineral in the microcrystalline groundmass; but it may be suspected that some portion of this is secondary. The rock is hornblende-biotite-diorite-porphyry (porphyrite).1

Type 3 (fig. 4, p. 486).—A third variety is typically audesitic in appearance and composition. It is free from quartz, with the disappearance of which the microscopic structure of the ground-mass changes: the felspars tend towards idiomorphism, flow-structure develops, and the proportion of coloured mineral (now chlorite) increases. Recognizable hornblende-pseudomorphs are abundant.

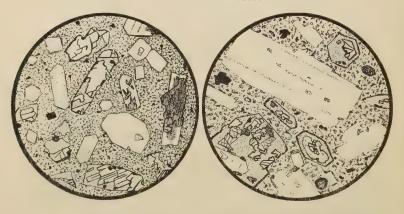
¹ It should be clearly understood that 'uralite-porphyry' and 'hornblende-porphyrite' are not synonymous terms, although they have been so used in the past. The former term should be restricted to augitic rocks in which the phenocrysts of this mineral have been converted into secondary hornblende, while the latter should be applied to intermediate rocks containing primary hornblende.

The arrangement of the two chief replacement-minerals (a narrow band of chlorite surrounding a central core of epidote) suggests that the crystals may have suffered from interaction with the ground-mass, in the manner so commonly seen in lavas of this composition.

In addition to the porphyritic types noted above, the rocks of many of the sills are devoid of prominent phenocrysts, and are of nearly equigranular texture. With the loss of the 'phyric' character of the femic minerals disappears one of the chief criteria

Fig. 3.—Dacite, eastern flank of Cerniau. \times 20.

Fig. 4.—Diorite-porphyry from a sill in the Ffestiniog Beds, Foel Cae Poeth. \times 20.



[Phenocrysts of albitized plagioclase on the right, altering to dusky zoisite; bipyramidal quartzes; and epidote-chlorite pseudomorphs after hornblende, in a microcrystalline ground-mass.]

[Albitized plagioclase and pseudomorphs after hornblende in a microcrystalline ground-mass of felspar, chlorite, and iron-ores. The pseudomorphs contain chlorite (faint stippling), yellow epidote (clear strong outline), calcite (cross-hatched), and iron-ores.]

for the identification of the rocks. They are now merely aggregates of secondary minerals, and any attempt to name the rocks would be hazardous without some knowledge of their associates. But the minerals present are the same as those occurring in the dacites, diorite-porphyries, and andesites. They occur in the same series of minor intrusions, and, so far as one can judge, are all of the same age. There is no doubt that the aphyric types were originally hornblendic rocks, differing from those described above in texture only. The accurate naming of these rocks is difficult. 'Porphyrite' suggests itself, as the rocks are hypabyssal equivalents of diorite and andesite, but the name is obviously inapplicable on account of the textural implication. Strictly they are aphyric

diorite-porphyries—a contradiction in terms which can best be

overcome by calling them microdiorites.1

In all these rocks the plagioclase has the optical properties of albite. It may be objected that this is not typical of normal andesites, but we are clearly dealing with a case of albitization of a more basic plagioclase, and it has been thought best to classify the rocks according to their regular characters.

From the foregoing account it will be seen that the sill-rocks from the west of Rhobell fall into line with those of other andesitic episodes. The range in composition is, however, not wide. The smaller volume of magma available for injection as minor intrusions, together with the shorter period of time involved, combined to prevent any marked departure from the composition of the average type, so that the acid felsites and quartz-porphyries which might have been expected to occur were not produced, or at least were not injected in the district under review.

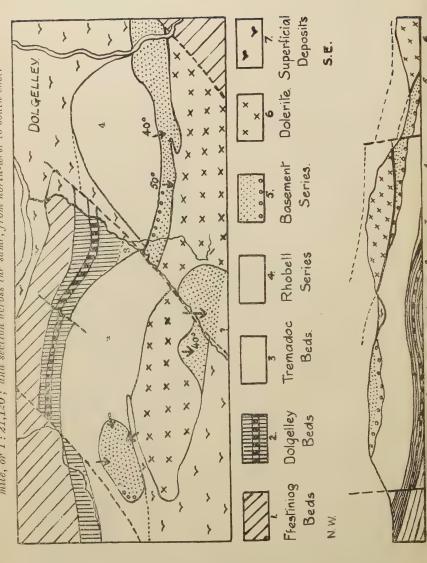
Other occurrences of hornblende-diorite-porphyries and allied rocks have been recorded from the region of the Harlech Dome. In his account of the Dolgelley 'Gold Belt' Dr. A. R. Andrew gives a brief description of the igneous rocks associated with the gold-bearing lodes in this locality, recognizing two chief types:

'diabase' and 'porphyries.'

As the two principal minerals are (in Type 1) oligoclase and hornblende, the term 'diabase' is not applicable, and a cursory examination of the rocks in the field proves them to be so like the sill-rocks of Rhobell as to leave no room for doubt that they belong to the same igneous cycle. The diorite-porphyry which furnished much building material for Dolgellev proves to be an important occurrence lying on the southern outskirts of that The rock previously mapped as 'diabase' consists in part of dolerite, but in part of hornblendic rocks similar to those described above. The latter are faulted against Ffestiniog Beds on the south-east, cut off by the Dolgelley fault on the northwest, and are bordered by the alluvium of the Wnion on the north. On the south only is the 'greenstone' in normal juxtaposition with other rocks: for a limited distance the Garth Grit rests upon it (270 yards due south of Clogwyn), and is succeeded by the wellbedded Basement Flags. The stratigraphical position of the 'greenstone' is thus clear-it lies immediately beneath what has been regarded as the local base of the Ordovician. These rocks are repeated on the north of the fault following the old Towyn Road. At the western extremity of the outcrop the base of the synclinal patch of Basement Group is seen near the top of the steep crag south-east of Maes Angarad farm. The basal grit is but feebly developed, being less quartzose than usual, though it contains a great number of the characteristic phosphatic nodules.

Cf. 'The Geology of Ben Nevis & Glencoe' Mem. Geol. Surv. 1916, p. 173.
 Geology of the Dolgelley Gold Belt' Geol. Mag. 1910, pp. 169-71.

Fig. 5.—Geological map of the district south-west of Dolgelley, on the scale of 3 inches to the mile, or 1:21,120; and section across the same, from north-west to south-east.



The lower part of the Basement Group differs little in general appearance from the underlying igneous rock, from the degradation of which it was obviously derived in part. The relationship of the various rocks in this locality is illustrated in the appended map and section (fig. 5, p. 488).

In the Deer Park low down on the southern slopes of Moel Offrwm the only rock exposed is a greenstone similar to that beneath the Garth Grit at Dolgelley and to the intrusions in the Ffestiniog Beds. At one small exposure north-east of the fish-ponds, the basal conglomerate itself is seen resting directly on the much-sheared greenstone, and contains phosphatic nodules and well-rounded bluish quartz-pebbles. Resting upon it is a grit 3 feet thick consisting of sharply angular quartz-grains an eighth of an inch across. An exactly similar grit occurs in the same stratigraphical position on the summit of Rhobell Fawr. The succeeding beds are the Basement Flags of the Arenig Series.

With regard to the origin of these 'greenstones' there are three possibilities to be considered:—(1) they are outliers of the Rhobell volcanic series; (2) they are later intrusions along the plane of unconformity separating the Arenigian from the Tremadocian; and (3) they are intrusions earlier than the period of erosion which preceded the deposition of the Garth Grit. The second possibility may be at once dismissed, as the Garth Grit shows no appreciable contact-metamorphism; while, where the same rock is cut by the later definitely intrusive dolerites, the amount of contact-alteration is always appreciable. Further, the state of oxidation of the iron in the greenstone immediately underlying the grit is different from that at greater depths exposed by subsequent denudation. This indicates weathering of the 'greenstone' prior to the deposition It should be possible to decide between alternatives of the grit. 1 and 3 by studying the lithological characters of the rocks and their contacts with contiguous strata. Unfortunately, the latter are not exposed, and important direct evidence is therefore unavailable. So far as the petrographical characters are concerned, the rocks of the two outcrops near Dolgelley are distinctly variable in texture and colour. A distinct banding (? bedding) is occasionally seen. Some of the rock-faces appear seoriaceous, while others are laced over with white-weathering slag-there can be little doubt that these rocks are extrusive, and the two patches of greenstone are outliers of the Rhobell Volcanic Group. The evidence is less conclusive in the case of the patch in the Deer Park. The variability noted above cannot be insisted upon-the rocks seem rather uniform in appearance; but, as already stated, they are badly sheared everywhere, and in places cleaved almost like slates. It is possible that they are intrusive; but, even if this be so, the rock loses none of its interest, as it must be a pre-Arenig intrusion uncovered by the post-Tremadoc erosion, and therefore forming part of the pre-Ordovician surface upon which the Garth Grit was deposited.

The sills in the Ffestiniog Beds are almost identical in mineral composition with the outliers mentioned above, while specimens from most of them can be readily matched in the Rhobell volcanic mass. Further, they belong to rock-types with a wide distribution in and around the Harlech Dome—that is, they belong to a regional series of minor intrusions. As in other, better-known volcanic episodes, the minor intrusions tended to concentrate about the centres of eruption. At present, only one of these has been located—the Rhobell centre; but attention may be drawn to a second marked concentration in the tract lying east of Trawsfynydd. The igneous rocks here have not been examined, but it is suspected that their presence indicates the position of a second eruptive centre. This group of intrusions lies due north of Rhobell along the same line of strike.

So far as petrographical characters are concerned, the descriptions given above establish the striking similarity between the sill-rocks and those belonging to the extrusive phase. Both are typical products of an andesitic magma. Thus petrographical characters, geographical distribution, and stratigraphical evidence unite in assigning these intrusions to the Rhobell Volcanic Series, of which

they are undoubtedly the 'hypabyssal' phase.

(f) The Age of the Volcanic Series.

Sir Andrew Ramsay's interest in the problems resulting from the volcanic nature of Rhobell Fawr is shown by his allotting a chapter and a half to the discussion of its age and origin. In the absence of definite stratigraphical and palaeontological evidence, he does not commit himself to a definite expression of opinion, leaving it to his readers to pass judgment on several hypotheses (which he discusses, however, in detail), and one gathers that he favoured the view that the volcano was a source of the 'Arenigian' lavas of the main Ordovician outcrop. He was evidently unaware of the occurrence of basal Arenigian grit on the summit of the mountain, and he could not have appreciated the petrographical dissimilarity between the two volcanic cycles.

Such was the case with J. Clifton Ward, who, although commissioned to make a special study of the mountain, failed to find the Arenigian sediments, except for a loose block. No actual evidence bearing on the main question is recorded, but Ward thought that the volcano marked the site of a post-Tremadoc centre of cruption, and commented upon the central position of Rhobell with reference to the great spread of 'Arenig' lavas and

ashes.2

² Ibid. p. 59.

Cole & Holland's discovery of the basal grit of the Arenigian on Rhobell Fawr led them to assign the volcanic outbreak to the Tremadocian, contemporaneous with the deposition of the Tremadoc Slates at Allt Lwyd and elsewhere. They further approved

¹ 'The Geology of North Wales' Mem. Geol. Surv. 2nd ed. (1881) pp. 54 & 71.

Ward's suggestion that the ejectamenta had sunk through the

shattered Lingula Flags in pre-Arenig grit times.1

Additional weight was given to their conclusions by the concurrence of Sir Archibald Geikie, who saw in 'the huge mountainmass of Rhobell Fawr.... some of the most stupendous memorials of the earlier eruptions' which began 'at the close of the deposition of the *Lingula* Flags.' He saw evidence elsewhere that 'intermittent outbursts occurred at many intervals during the time when the Tremadoc and Arenig beds were being deposited.²

Dr. Alfred Harker agrees with Prof. W. G. Fearnsides in regarding the rocks of Rhobell Fawr as being the products of the first outburst of igneous activity following the long period of quiescence which had ushered in the Palæozoic Era. The latter

writer hints at a pre-Arenig age for the eruptions.3

Recent investigations in both North and South Wales have shown that, in all the districts examined, this period of quiescence persisted until after the close of Tremadoc time, although the widespread vulcanicity of the Lower Llanvirn was preceded by outbursts at more than one level in the Arenig. In none of these areas is there any trace of volcanic activity at any level in the Tremadocian. I therefore approached the problem with the preconceived idea that the volcanic rocks would probably prove to be an outlier of the Arenig or Llanvirn Series. That preconceived idea soon proved wrong. The evidence noted above shows that the Rhobell Volcanic Group is earlier than the volcanic rocks of the main outcrop surrounding the Harlech Dome, and quite distinct from them in lithological characters.

There is no evidence to support the contention of earlier workers, that the eruptions were contemporaneous with the formation of the Tremadoc Slates. Of course, the suggestion was made at a time when the true nature of the break between the Tremadoc and the Arenig beds was not appreciated, and when none of the

surrounding districts had been worked out in detail.

The Rhobell Volcanic Group is post-Tremadocian, in the sense that it is later than any part of that series which survived the post-Tremadoc erosion in the immediate neighbourhood, and possibly anywhere round the Dome. The series definitely does not become interbedded with the grits of the summit of Rhobell Fawr,⁴ but is succeeded unconformably by what is, in all other parts of Southern Merioneth, the local base of the Ordovician. In that sense the series is pre-Arenigian. It could be allotted to one or other of these divisions only if palæontological evidence were forthcoming from the volcanic rocks themselves; but there is no horizon from base to summit which is in the least likely to yield

² Pres. Address, Q. J. G. S. vol. xlvii (1891) Proc. Geol. Soc. pp. 106-107 & 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 177.

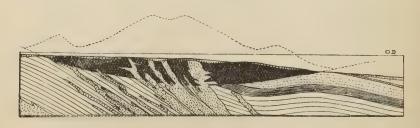
^{1 &#}x27;Structure & Stratigraphical Relations of Rhobell Fawr' Geol. Mag. 1890, p. 451.

A. Harker, Pres. Address, Q. J. G. S. vol. lxxiii (1917) p. lxxvi; W. G. Fearnsides, 'Geology in the Field' Geol. Assoc. 1910, p. 795.

4 Cf. A. Geikie, 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 177.



1. The volcanic pile resting upon the denuded Upper Cambrian strata.



In Garth Grit times, showing the local base of the Ordovician resting in hollows on the lower portion of the volcanic mass (which alone had escaped erosion), and on the Upper Cambrian rocks.



3. Present-day conditions, showing Ffestiniog, Dolgelley, and Tremadoc Beds, with the relic of the volcanic pile, penetrated by intrusions of diorite-porphyry.

The Basement Group of the Ordovician System rests upon the volcanic rocks in the centre and on the Tremadoc Beds in the east.

fossil remains, and it seems best to regard the series as partly filling the gap represented elsewhere by the unconformity separating

the two sedimentary groups.

It has been shown above that the volcanic mass rests upon different members of the Upper Cambrian succession down to the Lower Dolgelley Beds. This implies the removal during the post-Tremadoc erosion of more than 1000 feet of sediment. This amount is not excessive, compared with the 6000 feet removed in the Lleyn and the 5000 feet lost in Anglesey. In the Arenig district approximately the same amount of denudation took place as near Rhobell. The accumulation of the volcanic rocks themselves may have occupied only an inconsiderable period of time. Judging from the coarse grain of much of the material, and from the lack of marked differentiation, it is possible that they are the products of one great eruption.

With regard to the break above the volcanic rocks, it is difficult to gauge its importance; even had the Garth Grit been deposited immediately after the cessation of volcanic activity, there would have been a notable discordance between the volcanic material and the grit. But a large amount of levelling must have preceded the spreading of the grit over the surface, which consisted partly of Cambrian slates and partly of the Rhobell volcanic rocks, as is

shown in the series of reconstructions (fig. 6, p. 492).

Confirmation of the conclusions arrived at above is afforded by certain 'green beds' in the foot-hills of the Aran range. Attention was drawn to these fifteen years ago, but they still await full description.\(^1\) These rocks rest upon Tremadoc Slates the exact horizon of which is unknown, and are said to be succeeded by the true basal conglomerate of the Arenigian which includes exceptionally large and well-rounded pebbles of Foel Ddu felsite. Their presence emphasizes the long duration of the post-Tremadoc erosion. The stratigraphical position of these green beds is thus precisely the same as that of the Rhobell Volcanic Group, and they must be regarded as the attenuated representatives of the latter.

As pointed out above, the Rhobell Volcanic Group is unique in North Wales, in respect both of composition and of stratigraphical position, unless some of the igneous rocks near Trawsfynydd should prove to be extrusive. In a recent communication to the Geological Society a description was given of a similar volcanic series in the neighbourhood of Trefgarn (Pembrokeshire).² This also is essentially andesitic, and occupies an equally low position in

the Arenig Series.

W. G. Fearnsides, 'Geology in the Field' Geol. Assoc. 1910, p. 795.

² H. H. Thomas & A. H. Cox, 'The Volcanic Series of Trefgarn, &c.' Q. J. G. S. vol. lxxx (1924) p. 520. Prof. A. H. Cox informs me that the Lower Acid Series in the neighbourhood of Mynydd y Gader (north of Cader Idris) contains fragments of pseudovesicular andesitic rocks like those in the Rhobell Volcanic Group. Such rocks do not occur in situ in this district, but the fragments must have been derived from some now completely destroyed or hidden diorite-porphyry or andesite. As the volcanic series in which they occur is the lowest one in the district, they afford additional evidence of the early age of the rock that they represent.

V. THE ORDOVICIAN SUCCESSION.

(a) The Basement Group.

In the Arthog paper a description is given of the lowest division of the Ordovician, termed the Basement Series. and their outcrop is traced from near Arthog Station to a point three-quarters of a mile south of Dolgelley Station, the type-section being that in the neighbourhood of Llyn Wylfa.

In the Arenig district the corresponding strata were traced to a point south of Moel Llyfnant, approximately 4 miles north of the

appended map (Pl. XXXII).2

The equivalents of the Basement Group in the Rhobell district are more important than in either of these tracts, covering a considerably greater area and attaining a greater thickness. description given below supplements those already published. A threefold division, based on the lithological characters of the rocks, is found to be applicable over the whole district. At or near the base of the Group a thin and inconstant basal grit or conglomerate is developed, and is succeeded by about 100 feet of well-bedded flags. The latter pass up gradually into massive felspathic ashes, which are fully twice as thick as the flags. A detailed petrological account is given below.

(i) The northern part of the area. The main outcrop forms a prominent feature, on account of the greater resistance to weathering offered by its grits and ashes than by the Cambrian slates and shales upon which it rests. In the central part of the area the Basement Group overlaps on to the Rhobell Volcanic Group, and north-and-south folding has resulted in the separation of the outliers which cap the summits of Rhobell Fawr and Moel Cors-v-Garnedd, and build the lower slopes of Moel Offrwm in the south-west.

The flags, together with the grit at the base, form a picturesque waterfall where they cross the Afon Cwm Hesgen. Here it is quite clear that they are resting discordantly on the Bellerophon Beds, for a short distance farther north they overstep the latter, and come to rest on the Dictyonema Band. From this point they swing obliquely down the precipitous slopes of Allt Lwyd, which are capped by the massive ashes above. A fine dip-section is exhibited in the gorge cut through the escarpment by the Mawddach, where the effects of repeating strike-faults are demonstrable.3 On the high moorland tract to the south, separating Rhobell from Y Dduallt, there are few exposures. Ramsay believed the Arenig grit to be absent from this belt, suggesting that it was either overlapped by the ashes above or cut out by strike-faulting.

¹ A. H. Cox & A. K. Wells, Q. J. G. S. vol. lxxvi (1920-21) p. 265.

² W. G. Fearnsides, Q. J. G. S. vol. lxi (1905) p. 618. 3 The massive ashes high in the Basement Group yielded Calymene parvifrons to Prof. Fearnsides in this gorge.

Re-examination shows that the absence of the lowest Ordovician rocks is more apparent than real, and is accounted for by the thick upland peat which buries the solid rocks, but through which occasional island-like ridges of the Basement Group emerge. Although their base is not seen, blocks of a pure quartzose grit like that at Allt Lwyd, on the summit of Rhobell Fawr and at the foot of Moel Offrwm, are seen in the peat a short distance in advance of the first exposures, and are doubtless nearly in situ. The lowest rocks exposed are well up in the flags, which are succeeded by the massive ashes. Farther south exposures are poor, until the Afon Eiddon is crossed. This dip-stream, like the Mawddach, has provided a fine section, the massive false-bedded ashes building a series of imposing cliff-features. At the Afon Eiddon the Basement flags are at the foot and west of the hog-backed ridge of Moel Caer Defaid; farther south, they climb obliquely up the slope and form the prominent line of crags along the summit. Here the outerop is reduced in width by strike-faulting, which cuts out the Calymene Ash.

Isolated exposures enable us to follow the outcrop through the cultivated land on the south. Locally there are rapid changes in both direction and amount of dip, although south-east is now the dominant direction. Near Blaenau the relationship of the Basement Group to the Tremadoc Beds is again clear: the former

is resting directly on the Dictyonema Band.

(ii) The southern part of the area.—In the southern half of the district the Basement Group covers large tracts, including the continuation of the main outcrop traced above, the protrusion into the neighbourhood of Llanfachreth and Moel Offrwm, and several outliers, some of very small extent. The main outcrop continues in a south-westerly direction to a point between Bryn Brâs and Ystum Gwadnaeth, where it suddenly swings north-westwards for about a mile and a half. As shown above, this is due to a considerable fault with southward downthrow. At three points in the woods west of Cors-y-Garnedd the unmistakable basal conglomerate rests directly on volcanic rocks, and is succeeded by the well-bedded flags. These small patches—each about 2 square yards in area—are interesting as being the north-westernmost outliers of the basal conglomerate in the district.

With the exception of the woods north of Llanfachreth, where the beds form a series of step-like ridges striking north-eastwards, most of the ground occupied by the Basement Group is a waste of gorse and bracken, from which rise numerous tors with steep sides determined by joints, and nearly flat tops which are dip-faces modified by glaciation. The abnormal width of outcrop in the neighbourhood of Llanfachreth is due in part to the north-and-south thickening, in part to folds of small amplitude, but chiefly to the fact that the sheet-dip of the beds approximates to the general gradient of the ground. From a favourable view-point the Basement Group can be visualized as a composite sheet, some

300 feet thick, gently crumpled, and dipping at an angle of about 20° towards the Wnion valley. The deep valley stretching southwards from near Llanfachreth is thickly plastered with drift mainly composed of blocks of Basement Group material, including much of the actual basal conglomerate; while occasionally the bedded flags near the base are exposed in situ—as, for example,

south of Llyn Pwll-y-Gele.

Passing now to Moel Offrwm, it may be noted that, on the north, west, and east, the dip is into the hill at steep angles near the foot, though diminishing upwards. Obviously, then, a shallow flat-bottomed syncline passes almost centrally through the hill, the complementary anticline passing close to its eastern flank. As recorded above, the basal grit is again exposed resting upon the earlier igneous rocks, while the flags and massive ashes form a steep scarp terminated upwards by a prominent shelf on all sides but the south.

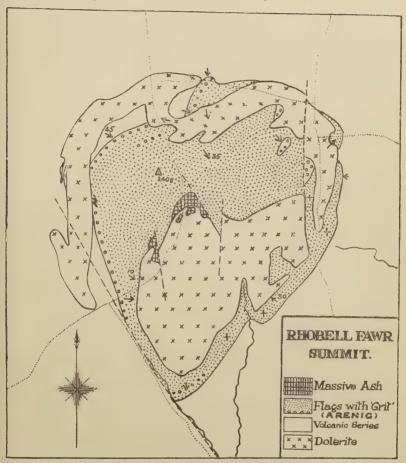
From Moel Offrwm the Basement Group ranges down into the Wnion valley where it is cut off by the Dolgelley fault. the gorge of the Wnion, half a mile west of Rhydymain Post Office, the Tremadoc slates are succeeded by the Basement Group, with no demonstrable discordance, the more massive members causing a notable narrowing of the river, and a succession of rapids where it is spanned by the bridge, $5\frac{1}{2}$ miles from Dolgelley.

From the foregoing account it will be inferred that the actual base of the Ordovician, though invisible over the greater part of the area, is clearly exposed at a number of isolated and widely separated localities. As a special study of the rocks of Rhobell Fawr was made, and as the exposures by reason of their altitude are particularly clear, a fuller account of the Basement Group as there developed will be given.

(b) The Rhobell Fawr Outlier (fig. 7, p. 497).

The detailed survey has shown that the Basement grits vary in thickness from 4 feet to nothing, and that, together with the overlying flags, they form a ring-like outcrop surrounding the The plane of unconformity upon which they rest has provided a plane of easy passage for the intrusion of basic sills, and on this account their outcrop is somewhat broken. On the north, west, and east dolerite bounds the outlier, but on the southeast the flags of the Basement Group form a narrow band separating the sills from the underlying Rhobell volcanic rocks. Within the ring of dolerite the ground is almost wholly occupied by the Basement flags. Denudation has removed the overlying massive ashes, with the exception of a small patch occurring in contact with the dolerite south of the summit-cairn. A southeastward dip is maintained over the greater part of the outlier, though a gentle undulation can everywhere be seen. At one point a small pitching anticline brings the basal conglomerate to the surface, while the only notable exception to the south-eastward sheet-dip is along the south-eastern border of the outlier, where the dip is north-westward—under the dolerite at a small angle (Pl. XXXI, fig. 2).

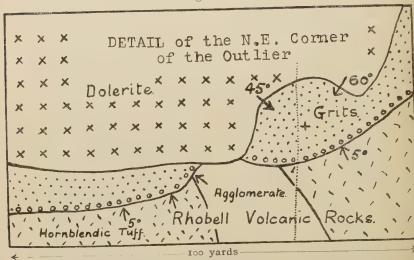
Fig. 7.—Scale: 8 inches=1 mile, or 1:7920.



If the usual route from Llanfachreth to the summit of the mountain is followed (from the top of Bwlch Goriwared past the Shepherd's Well), the rocks are first encountered on the far side of a steep-sided fault-notch. The basal grit climbs obliquely up the hillside, into which it dips at about 10°. Following its outcrop north-westwards we encounter it sometimes above, sometimes below, the thick sill which forms a prominent feature.

The grit attains its maximum thickness (4 feet) in the outcrop north-west of the summit, but does not lie at the base, being underlain by about 8 feet of flags, identical in lithology with those above. The grit itself is quartzose polygenetic conglomerate, variable in grain and in the number of included pebbles of quartz, quartzite, and fine-grained sandstone. These are always well rounded, and were probably derived at second hand from some pre-existing sediment. The pebbles of andesite are also well rounded, but can be matched in the underlying volcanic series, and are of local origin. With regard to the so-called 'pisolitic shale-pebbles', these are restricted in this district to this low horizon, although siliceous and andesitic pebbles occur sporadically all through the Basement Group. They are not unique, however, as

Fig. 8.



their occurrence is recorded at Arenig in the lower ash-band in the *Hirundo* Beds. They are described as 'nummulite-like pebbles of friable shale which agree exactly in character with the masses described... in the basal Ordovician grit of Rhobell Fawr'. They are dark brown to black, but weather nearly white. When in this condition, and on account of their irregular rounded form and strongly marked concentric structure which becomes accentuated on weathering, they bear a certain deceptive resemblance to algal growths. With regard to their origin, the suggestion that they are isolated pisolites washed out of the Arenig shale involves an assumption which cannot be substantiated. The rock in which

¹ W. G. Fearnsides, 'The Geology of Arenig Fawr & Moel Llyfnant' Q. J. G. S. vol. lxi (1905) pp. 621-22.

² See G. A. J. Cole, Geol. Mag. 1893, p. 345.

they occur is nowhere preceded by Arenigian shales. Their occurrence is not recorded from any part of the underlying Tremadocian; hence it seems reasonable to suppose that they are concretions

formed during the post-Tremadoc erosion.1

The pebbles are embedded in an abundant matrix of subangular quartz-grains, often of a bluish opalescent variety, together with fewer white felspars of small size. The rock usually has a bluegrey coloration, on account of the chloritic base. The resemblance of some specimens of this rock to the grits of the Harlech Dome is very striking; but whether the basal Ordovician grit is merely redistributed Harlech Grit, or was derived from the same pre-Cambrian source, is difficult to decide. It may be remarked, however, that horizons as low as the Rhinog Grits were elsewhere exposed by the post-Tremadoc erosion, and that there is reason to believe that the north-and-south folding of the Dome was initiated at this time. The lithology of the 'grit' is quite distinctive. Wherever it occurs it has the same lithological features. It cannot be matched at any other horizon within the area mapped, which compensates somewhat for its unfossiliferous nature. Now, it has been shown above that the same grit elsewhere in the district rests upon different parts of the Tremadocian. The relationship of the grit to the Rhobell Volcanic Series is clearly demonstrated along the south-eastern margin of the outlier. Both here and on Moel Cors-v-Garnedd the Basement Group rests upon an originally flat, and hence denuded surface of volcanic rocks. When examined in detail, it is found that the surface, though generally flat, has many irregularities: at one point the grit spans a small hollow in the volcanic rocks, filled with sandy, poorly bedded sediment, while not far distant an instructive exposure shows the grit with overlying flags resting upon a hummocky surface of igneous rocks, partly agglomeratic, partly the intrusive hornblendic 'andesite' (fig. 8, p. 498). The flags above the basal grit are characterized by a rapid alternation of harder and softer bands, the differential weathering of which causes a strong 'ribbing' on exposed jointfaces. The laminæ are thinnest at the base of the flags, being as thin as sheets of paper and wedge-bedded. Higher in the series. although the bands of both kinds of sediment increase in thickness, the proportion of shale steadily diminishes. The rocks are very variable: specimens essentially shaly in character, but nevertheless containing thin partings of ash, can be collected from within an inch or two of massive felspathic bands with only thin shaly partings. As the latter are dark and much like the Tremadocian shales, while the former weather almost white, a rock of distinctive appearance results. The effects of contemporaneous erosion are

One of the concretions from the exposure south of Dolgelley has been submitted to chemical analysis, and proves to be fairly pure calcium-phosphate, with a small amount of iron as impurity. Their presence in the basal grit proves that a definite period of non-deposition ensued between the close of the Rhobell volcanic episode and the formation of the Arenigian sediments.

Fig. 9.—Geological sketch-map of Moel Cors-y-Garnedd, on the scale of 8 inches to the mile, or 1:7920.

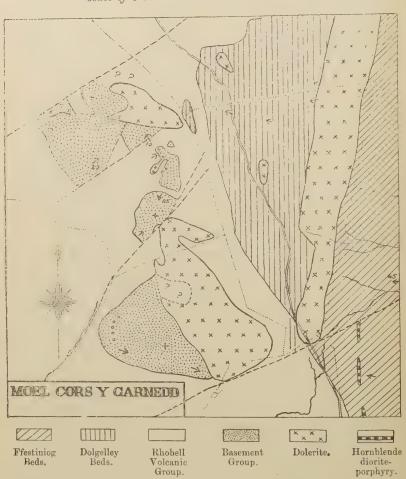


Fig. 10.—Sketch-section across Moel Cors.y-Garnedd, from the summit south-south-astrands.

S.S.E.

N.Z.X

seen in the frequently false-bedded and ripple-marked strata. false bedding is not so pronounced as in the massive ashes above, the angular discordance between successive bands being only

slight (Pl. XXXI, fig. 1). Shale-partings are often represented by layers of pellets: the argillaceous layers had evidently been broken up, and rolled into pellets before burial beneath the succeeding deposit of fel-Circular sections across wormspar-chips. borings filled with coarser sandy material are very common on bedding-planes, in some parts so much so that there seem to be nearly as many vertical partings as horizontal ones.

The general resemblance of these deposits to certain parts of the Ffestiniog Beds is so close that it is difficult to distinguish between them, while even more closely similar are the lowest parts of the Basement flags and the highest parts of the Asaphellus Flags as they are developed between Arenig and Moel Llyfnant. Thus what appears on casual inspection to be exactly the same type of lithology occurs at three different horizons, and necessitates the exercise of much care when dealing with isolated exposures in faulted country. The pale layers in the Basement flags are, however, coarser and more essentially felspathic than in the Thin sections show the other two cases. pale layers to be composed of irregular, sharply angular felspar-chips, chiefly acid plagioclase, together with quartz showing strain-shadows, occasional patches of limpid chlorite, and pieces of chert, all very similar to constituents of the basal grit.

The massive ashes above the flags were certainly deposited under water, but they are essentially felspathic, and pyroclastic in origin, being derived from the disintegration of some not far distant volcanic cone. But the argillaceous component of the flags below still makes its appearance at intervals as tough shaly layers measuring up to 3 inches in thickness, but usually taking the form of mere dark wisps streaking the paleweathering 'ash.' In the thicker bands a minor lamination suggestive of a double

On the whole, however, these rocks are singularly rhythm is seen. uniform in composition and characterless in appearance. Except

[Length of section = 300 yards.

where buried in the peat east of Rhobell, they are excellently exposed, and their features may be studied at any point on their outcrop. Throughout many feet of their thickness they show but little trace of stratification, while (especially in the lower part) the discovery of a quartz-pebble in them is an uncommon event. However, careful examination of the massive joint-faces frequently reveals a strong (though poorly defined) current-bedding of the torrential

type. Occasional thin spreads of conglomerate occur, and are not restricted to any particular horizon. They do not exceed a foot in thickness, and they invariably thin right out in the course of a few yards. The pebbles up to 4 inches in diameter in these bands are well rounded and ovoid in shape, and are chiefly of igneous rocks, including a pale-grey felsite indistinguishable from that occurring at Foel Ddu in the Aran Mountains. These massive ashes are worked for road-metal in a number of small quarries, so that plenty of fresh material is available for study. rock is grev and featureless, but the weathered surface shows a medley of felspar laths and chips. The closest examination is necessary to distinguish these rocks from some of the dolerites. This is notably the case on the rugged slopes of Moel Offrwm, above the Deer Park, where the two rocks are closely associated. Both are equally massive, equally resistant to weathering, equally

well glaciated, and both are jointed in the same way.

With regard to correlation of the Basement Group, the basal conglomerate is the equivalent of the Garth Grit of other districts; the Basement flags reproduce in all details the lithology of the Extensus Flags of Arenig Mountain, and especially on Rhobell give rise to the same terraced type of scenery as that equally well developed on the steep slopes of Moel Llyfnant. The only noteworthy difference in lithology is the slightly greater coarseness of grain, coupled with increased thickness of individual laminæ. Both differences are the result of closer proximity to the source of supply of the sediment, which may also account for the unfossiliferous nature of the flags in the Rhobell district. The succeeding massive felspathic ashes are in general very similar in appearance, constitution, and lithological features to the Calymene Ash of the Arenig district, and there is no doubt that the one is the lateral equivalent of the other. The total thickness has increased considerably, however, especially in the neighbourhood of Llanfachreth, while certain parts are much coarser in grain. On the south, in the Arthog-Dolgelley belt, the Calymene Ash resumes its normal characters, and is of much diminished thickness, although on exactly the same stratigraphical horizon, and showing exactly the same lithological features as at Arenig and Moel Llyfnant. It is believed that the Calymene Ash of the latter district was derived from 'some more or less distant volcanic source, which, judging by the thickening and increase of ashy material southwards, probably lay in that direction'. It may

¹ W. G. Fearnsides, 'The Geology of Arenig Fawr & Moel Llyfnant' Q. J. G. S. vol. lxi (1905) p. 619.

now be suggested that this volcanic source lay east of Rhobell Fawr, and is thus buried beneath later rocks. Although the actual vent cannot be located, it was sufficiently near to deposit coarse ash with lapillar bands north of Moel Caer Defaid.

VI. THE LLANVIRN-LLANDEILO SUCCESSION.

The description of the strata lying between the Basement Group and the main volcanic outcrop is divided into two parts.

(a) Moel Offrwm.

The Basement Group on Moel Offrwm encircles the hill completely. On the north, west, and east a small thickness of shale, not exceeding 15 feet, supervenes. Although yielding nothing but an occasional Lingula, from their stratigraphical position the shales may be correlated with the Hirundo Shales, which they resemble in lithology. Exposures of these beds are poor, the best being on the eastern side of the hill, where at one point they are seen on a glaciated pavement which forms a prominent shoulder The bedding and cleavage are unfortunately on the hillside. opposed, which accounts at least in part for the difficulty of obtaining fossils. A point of rather exceptional interest is the occurrence at the same horizon of a pisolitic iron-ore on the other side of the hill (above Nannau). It is well known that this peculiar rock-type occurs at more than one level in Merioneth and Carnarvonshire, the best-known example maintaining a fairly constant horizon in the zone of Nemagraptus gracilis. Lithologically, the Moel-Offrwm ore is similar to specimens from this zone at Tremadoc, Cross Foxes (Cader Idris), and Anglesey, but is presumably at a considerably lower horizon-high in the Arenigian. This interesting occurrence makes the failure of the palæontological evidence the more regrettable. The shales become ashy upwards, passing rather suddenly into the overlying volcanic group.

The rhyolitic group.—These rocks are also best exposed on the eastern side of the Moel, where its two members form a prominent double scarp above the flat determined by the shale-band. The lower part is a rough-weathering ash with a whitish crust, and a streaky blue-grey interior. It contains lenticles of toughened shale, lapilli, and small porphyritic crystals, just large enough to be seen with the naked eye.

Under the microscope the rock proves to be a typical acid vitroclastic tuff, consisting of the finest dust, in which are embedded shards of altered glass, fragments of devitrified pumice. and numbers of well-formed crystals of quartz, orthoclase, and acid

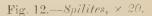
plagioclase (fig. 11, p. 504).

The massive rock above is somewhat problematical. In general appearance, colour, weathering, and jointing it seems to be a typical Ordovician rhyolite; but, in view of the proximity of

massive dolerites, and recognizing the lithological homocomorphy which exists between contact-altered ashes, adinoles, and some rhyolites, it is perhaps unwise to claim the rock as a flow, although it is certainly rhyolitic. It was doubtless this rock which Sir Andrew Ramsay had in mind, when he wrote:—

'While some of the strata [of Moel Offrwm] seem to be ordinary felspathic ashes, much of the material suggests the idea that it consists of ashy beds that have been subsequently altered and baked by heat, probably connected with the associated greenstones.' ('The Geology of North Wales' Mem. Geol. Surv. 2nd ed. 1881, p. 53.)

Fig. 11.—Quartz-keratophyre tuff, Moel Offrwm, × 20.





[Idiomorphic felspar and quartz in ash showing typical vitroclastic structure, some shattered: the felspar has inclusions of magnetite and zircon.]



[a=Marginal portion of flow, Dduallt. Scattered felspar-microlites embedded in a base of altered glass which contains many vesicles filled with granular quartz (clear), chlorite (stippled), fiddingsite (close stippling), and calcite (cross-hatched).

b=Spilite from Bryniau Cogau, southeast of Ddualt. Curved, bifurcating and pronged microlites of albite with patches of chlorite, embedded in a base containing epidote and iron-ores.]

Assuming the suggested correlation of these rocks with the Lower Acid (Mynydd-y-Gader) Group of Cader Idris to be correct, one naturally looks for the *Biftelus* Beds to follow. A thin band of ashy shale is certainly seen at one point, but no fossils were obtained, so that it must remain doubtful whether this insignificant band represents the 600 feet of these beds at Arthog. More basic ashes supervene, bearing a strong resemblance to the Cefn-Hir Ashes of the Cader Idris country. Agglomeratic bands alternate with thin layers of finer well-bedded ashes, clearly exposed on the southern and south-western slopes of the hill. Near the top of

the series a spilite-flow, some 30 feet in maximum thickness, occurs. Judging from the inadequate exposures available, it appears to be a good example of its kind. The massive lower part resembles finegrained dolerite, while pillow-structure is developed in the upper portion. In a small outcrop on the shoulder above Nannau a few exceptionally well-formed pillows are seen. They are oval in cross-section, with a compact (originally glassy) outer skin, while the abundant vesicles show the grading in size and concentric arrangement characteristic of these rocks, but seldom seen in the Although at this point there is no foreign material between the pillows, elsewhere along the outcrop the usual shaly wrappings occur. The spilite passes near the summit of the hill, and is followed by a small thickness of brown-weathering ashes. In the Arthog-Dolgellev district spilitic flows with associated ashes occur at two levels, in the Lower and in the Upper Basic Groups respectively. Although it would be unreasonable to expect a volcanic series to maintain a constant lithology over any considerable distance, the fact remains that the spilite and ashes of Moel Offrwm bear a very striking resemblance to the Lower Basic Group of Cader Idris and to the Platy and Agglomeratic Ashes of Arenig Mountain, and there can be little doubt that they are parts of one spread.

The succession on Moel Offrwm terminates in shales well exposed in a steep section immediately east of the summit, and on the glaciated pavement capping it. Again, the directions of bedding and cleavage are opposed, and the beds have failed to yield

any palæontological evidence of their horizon.

(b) The Northern Part of the Area.

At almost any point on the main Ordovician outcrop between Allt Lwyd and the southern end of Craig-y-Benglog, clear dipsections are available for study, and a dip-traverse anywhere between these two points gives the general succession:

- 3. Volcanic Group.
- 2. Shales and Mudstones.
- 1. Basement Group.

The shales above the Basement Group are but indifferently exposed, the greater part of their outcrop being concealed beneath peat. The highest beds of the Basement Group exposed on Moel Caer Defaid dip almost vertically into the hollow occupied by the shales, from which they are separated by strike-faults. Three localities for fossils have been discovered, one near the lower (western) margin of the shales, and the others near the base of the overlying volcanic group.

At the bend in the Afon Eiddon strongly colour-banded, rustyweathering shales have yielded at certain horizons numbers of large tuning-fork Didymograptids, such as occur at about the middle of the Llanvirn Series. The shales are capped by a tough slaty ash, the eastward-dipping upper surface of which forms a small river-cliff connecting this exposure with one farther north.

Here the ash strikes in behind a small thickness of intensely black, well-banded, very pyritous shales, yielding a black streak. They dip steeply eastwards, there is coincidence of bedding and cleavage, while certain bedding-planes are literally covered with poorly preserved graptolites, for the greater part indeterminable, being mere white streaks on a black ground. Those sufficiently well preserved for identification include Dicellograptus sextans Hall, Dicranograptus rectus (?) Hopkinson, Glyptograptus teretiusculus var. siccatus Elles & Wood, G. teretiusculus var. euglyphus Lapworth, Hallograptus mucronatus (Hall), and Climacograptus sp. These constitute a characteristic assemblage of forms from the zone of Nemagraptus gracilis.

About a mile away to the south, and in the base of the volcanic group, graptolites, the state of preservation of which again leaves much to be desired, were obtained from dark-grey mudstones, exposed to the thickness of 4 feet in the right bank of the stream draining northwards from Y Fron. Fossils, though moderately plentiful, are restricted to a small number of forms. The commonest is a Glyptograptus, apparently G. teretiusculus Hisinger, associated with an occasional Mesograptus priscus Elles & Wood and Callograptus. In addition to the graptolites, a large Lingula

and Siphonotreta micula M'Coy also occur.

On account of its bearing on the age of the volcanic group above, the relation of the various fossiliferous bands to one another assumes considerable importance. The Llanvirn Beds in the Afon Eiddon are in their correct position. They, as well as the higher black shales yielding the *Nemagraptus-gravilis* fauna, are dipping concordantly with the overlying volcanic rocks and at much the same angle. The mudstones with *Glyptograptus* are higher still, and at the base of the volcanic group. The whole shale series appears to constitute a normal ascending succession lying below and passing gradually up into the volcanic group, which must hence be of *Nemagraptus-gravilis* age.

Unless strike-faulting accounts for the marked northward thinning of the shale-band, it is clear that the succession is considerably condensed when compared with that at Cader Idris, and is rapidly approximating to the thickness of the Olehfa Shales of the Arenig district, to which the Rhobell deposits are lithologically

similar.

VII. THE MAIN VOLCANIC GROUP.

(a) The Pyroclastic Rocks.

As stated above, the fossiliferous mudstones are succeeded directly by volcanic rocks. There is no doubt that the junction is a normal one: less than 3 inches above the highest level from which fossils were obtained, the mudstone becomes charged with broken felspar-chips and small fragments of pale igneous rock.

These rapidly increase in number upwards at the expense of the normal sediment, which is completely replaced by ash in a few inches. Near the base, however, thin irregular bands of shale occur, but always charged with felspar-chips, while an ash-band is found below the fossiliferous mudstone on Y Fron.

The large proportion of pyroclastic material found in other spilitic districts has frequently occasioned comment. In the Llanfachreth area, although actual lava-flows are found at various levels, the greater part of the series consists of tuffs of rather fine grain. As is generally the case with a volcanic series, there are coarse explosion-tuffs at the base, containing many fragments of well-bedded shale, together with more abundant and larger pieces of a grey vesicular felsite. These are found to contain numerous small phenocrysts of quartz and felspar, and were evidently derived from a rock not unlike the Foel-Ddu felsite. The actual source of this material has not been located, but it is significant that the fragments are most prominent in the latitude of Dduallt; they decrease both in size and in number on the north and on the south, being absent at Allt Lwyd, and scarce south of Craig-y-Benglog. Thus the volcano supplying the felsite must have been situated east of Dduallt. The rock-fragments in these agglomeratic ashes are embedded in a matrix which is practically a crystal-tuff. The latter becomes the dominant type in the lower half of the series. It is of distinctive appearance, consisting of coarse chips and broken crystals of plagioclase, closely packed in a dark chloritic There is very little variation in texture, but the bedding is sometimes distinct on weathered surfaces. These tuffs are of exactly the same lithological type as those in the Upper Basic Series of Cader Idris, as, for example, on Mynydd Moel. In the field the term 'banded ash' was applied to them, so as to distinguish them from the 'agglomeratic ash' below and the 'siliceous ash' above. The last-named is quite different in appearance from the underlying beds, being of much finer grain. Its toughness is exceptional; it weathers very dark with an unusually rough surface. Bedding is much less distinct than in the crystal-tuffs, and parts are quite flinty and featureless. Examination of thin sections proves it to be indistinguishable from some parts of the Upper Acid Group, but what portion of the abundant quartz is primary and how much is secondary cannot now be determined.

The siliceous ashes are succeeded by more felspar-crystal tuffs like those near the base of the series. In this part of the succession the best pillow-lavas are found (on Dduallt and Bryniau Cogau), while at different levels spilitic breccias occur, similar to those described from Llanwrtyd Wells by Prof. L. D. Stamp & Mr. S. W. Wooldridge. It is doubtful whether any of these is actually agglomeratic; certainly none of them indicates the site of a vent (as they do at Llanwrtyd), but probably they are brecciated flows. In addition to the actual lavas, transgressive basic sills

¹ 'The Igneous & Associated Rocks of Llanwrtyd' Q. J. G. S. vol. lxxix (1923) pp. 20 & 34.

occur at all levels in the series. Although definitely transgressive (in one case from the volcanic series into the underlying slates), some of them so closely resemble the flows as to deceive the unwary. In place of the pillow-structure exhibited by the lavas, the sills are often beautifully columnar, the hexagonal columns averaging 12 inches across. They are rarely vesicular.

The volcanic group terminates upward in a well-developed pillow-lava (spilite) which forms a prominent strike-feature on the lower slopes of Dduallt, plunging steeply down under the

succeeding slates.

(b) The Basic Lavas.

The basic rocks of the Llanfachreth district merit somewhat special treatment, as their study sheds light on the formation of

pillow-structure and the status of the spilitic suite.

It has been recognized for some time that the lavas of Ordovician age in North Wales, especially those occurring at lower levels than the 'Snowdonian Volcanics', exhibit strong affinity with the spilitic suite. It has been shown that the basic lavas are usually spilites, that those of intermediate composition are keratophyres, while the acid flows are quartz-keratophyres.1 Although detailed work in districts which have been re-surveyed since the publication of Prof. Cox's paper has gone far towards, establishing the truth of this suggestion, Prof. Fearnsides's account of Arenig Mountain and Moel Llyfnant shows that the andesitic lavas there developed fall in a different category. Recent work has proved that the main eruptions in the Arenig Mountain and Cader Idris districts, though approximately contemporaneous, were not co-magmatic. The delimitation of the two petrographical provinces and the causes of the differences remain unexplained. From the Llanfachreth district, centrally situated between the two areas, crucial evidence bearing on these points might reasonably be expected.

It soon became apparent in the course of the present research that the hypersthene-andesite magma of Arenig had failed to penetrate to the neighbourhood of Rhobell Fawr, and that the lavas had affinity with those of Cader Idris rather than with those of Arenig Mountain. Although the rocks do not in many cases differ essentially from spilites of other districts, certain of them show a distinct departure from the normal type, particularly in the almost ideal state of preservation of their component minerals. This attracts attention, as spilites generally merit their unenviable reputation of being in a highly altered condition.

(i) Field Occurrence.

The pillow-lavas of the Llanfachreth district have been traced from some distance north of Allt Lwyd, beyond the boundary of

¹ A. H. Cox, 'Igneous Rocks of Ordovician Age' Rep. Brit. Assoc. (Birmingham) 1913, p. 496; A. H. Cox & O. T. Jones, 'Pillow-Lavas in North & South Wales' Geol. Mag. 1913, p. 516.

the map, nearly to the valley of the Wnion in the south. They are best exposed on Dduallt, Y Fron, and Craig-y-Benglog. Beyond Cwm Hesgen they have not yet been traced; but they cannot extend much farther north, as they are definitely absent from Moel Llyfnant, and must die out in the inaccessible tract between the two districts. They thicken southwards, and it is probable that their source was near Craig-y-Benglog. The lowest flows were preceded by the emission of large quantities of ash which, if we judge from their well-bedded character, must have been submarine. The highest flow on Dduallt is immediately succeeded by a considerable thickness of grey shale, while the thinner flows at lower levels are also as a rule overlain by thin shale-bands. Consequently, the possibility of intrusion along shale-bands rather than actual extrusion was suspected. The lower parts of the flows on Dduallt are slaggy and brecciated, while portions of the underlying ash have been caught up and incorporated. The higher parts are more compact, and pillowstructure, becoming better developed upwards, makes its appearance. Some flows are again slaggy on the top. Although the underlying ash has been baked, the overlying shale is not appreciably indurated; it is neither bleached nor spotted, and breaks away from the surface of the pillows like the skins of an onion. The available evidence is thus strongly in favour of an extrusive origin for these rocks. The frequent close association of lava and shale mentioned above must have resulted from the periodic exhaustion of the energy of the volcano, following the outpouring of each flow. During the short period of normal sedimentation which ensued shale was deposited, while the succeeding eruption commenced with explosive violence and the formation of more pyroclastic rock.

When the lowest lava on Y Fron is examined, it is seen that the normal spilite of the higher flows has given place to two different rock-types. The flow is first seen at the Afon Eiddon, where it shows moderately well-developed pillow-structure exposed on a dip-slope. Thence it can be traced up the hill, being frequently shifted laterally by cross-faults. On the southern face of the hill a fine cliff-section yields eminently satisfactory exposures. A finely crystalline grey rock builds the lower portion of the flow. and resembles the finer-grained dolerites of the district so closely as to be indistinguishable from them. It is traversed by massive joint-planes, and an extrusive origin would not be suspected were it not for the overlying pillowy portion. The latter makes up the topmost third of the flow in the west; but, at its eastern end, where it is much thinner, it is pillowy throughout, and small apparently isolated pillows occur in the ashes. This part of the flow (variolite) is very compact and of much finer grain, while it has a dark mauve colour, quite unlike any other rock in the neighbourhood, but closely resembling the well-known (though as yet undescribed) pillow-lava at the summit of Pen-y-Gader. Pillow-structure is restricted to the variolite, and the pillowy portion is always of this rock-type. The variolite grades insensibly into the doleritic portion. It was thought that the close association of the two types might have resulted from the injection of a thin dolerite along the strike of a pillow-lava, similar to the example described by Dr. R. L. Sherlock from Brent Tor 1; but the failure to find any evidence of intrusion, and the perfect transition from one to the other, render the view untenable. It may here be remarked that exactly the same features are exhibited, and the same difficulty of interpretation was encountered when the spilites of New South Wales were examined by Prof. W. N. Benson. This writer has described sills (which are nevertheless pillow-lavas) with which

'are associated massive intrusive dolerites quite indistinguishable in the hand-specimen from the rock in the centre of the pillows and it is often difficult to determine whether there is a passage from the pillowy rock into the massive dolerite, or whether there is a boundary between them.

The pillows bear but little resemblance to piled bales of cloth as do certain other well-known examples, such as those of Pen-v-Gader, of Chipley in Devon, and Pentire in Cornwall. They have the form of large, irregular, bulbous masses with smooth surfaces from which rise occasional projections -the frozen 'buds' of J. V. Lewis,3 while the necks from which expanded buds were broken by the onward motion of the lava are occasionally seen (Pl. XXX, fig. 2). The pillows range in size from 4 inches to several feet across. Interstitial material is always small in amount, and is invariably shale, and never the chert, jasper, or limestone found in similar cases elsewhere. The concentric structure resulting from the regular disposition of vesicles and varioles is usually absent; not a single hollow pillow has been observed, although many of them show a few radial gaping cracks, closing towards the outside of the pillow containing them, and evidently the result of contraction (Pl. XXX, fig. 2). It is obviously impossible to use Dewey's apt analogy and to liken these pillows to 'gigantic, thick-walled bubbles'. The lavas are identical in appearance with that photographed by Tempest Anderson and reproduced in the important and much-quoted paper in which are recorded the results of a ropy lava entering the waters of a lagoon.4 The resulting pillow-structure is strictly comparable with that of the rocks under discussion, and is very different in appearance, and (one can scarcely doubt) in mode of formation also, from the typical examples mentioned above. However this remarkable structure may have arisen in the Devonian and Cornish instances, I have no doubt at all that those pillow-lavas that I have examined were formed in the way outlined by J. V. Lewis. There can be no

Geology of Tavistock & Launceston 'Mem. Geol. Surv. 1911, p. 40.

² 'Geology & Petrology of the Great Serpentine Belt of New South Wales: pt. iv' Proc. Linn. Soc. N.S.W. vol. xl (1915) p. 128.

³ Bull. Geol. Soc. Amer. vol. xxv (1914) p. 592. 4 'Volcano of Matavanu in Savaii' Q. J. G. S. vol. lxvi (1910) p. 632 &

⁵ J. V. Lewis, op. jam cit. p. 592; A. K. Wells, 'The Problem of the Spilites' Geol. Mag. vol. lx (1923) p. 63.

question of pillows, several feet in diameter and containing scarcely a vesicle, being buoyed up in the water. Proof is wanting that any individual pillow is completely separated from contiguous ones, and these flows are evidently closely related to those of the pahoe-hoe type, owing their differences to extrusion under water.

(ii) Petrography.

The spilites.—The spilites of the Allt Lwyd-Dduallt belt differ among themselves in texture and degree of alteration, but all are far removed, so far as freshness is concerned, from the basalts and variolites described below. Unweathered samples of the main flow on Dduallt are fine-grained, rather pale-grey in colour, and very vesicular. In the case of the higher flows, in addition to the many small vesicles, there occur more widely spaced calcite-filled pipe-amygdules, several inches long and about three-eighths of an inch in maximum diameter.

Under the microscope the rocks are seen very closely to resemble spilites from other localities. The only essential minerals are plagioclase (albite) in tiny lath-shaped sections, chlorite, and ilmenite, together with much irresolvable material including, however, a moderate amount of epidote and zoisite. The outer portions of the flows were doubtless glassy. In these the albite is microlitic, the characteristic forked terminations being quite common, while there are fewer hollow rectangular cross-sections. In coarser-grained specimens the plagioclase occurs in stouter laths, the majority being slightly bent, while some are strongly curved. They are suspiciously clear, although it is difficult to prove the albite in them to be either definitely primary or secondary—the lime-silicates in the base were derived at least in part, from the decomposition of the original augite (fig. 12 b, p. 504). The few scattered microphenocrysts of slightly more basic composition are in a better state of preservation than the microlites of the groundmass. Multiple twinning is rare in these felspars. The vesicles show considerable variation in the nature of the infilling minerals, of which the chief are pale-green chlorite, calcite, chalybite, quartz. chalcedony, albite, pyrite, and a micaceous mineral. The majority contain chlorite and calcite, the easy removal of which by weathering gives to the rocks a characteristic honeycomb appearance. Less commonly the infilling mineral proves more resistant to weathering than the parent rock, causing the rock-face to be plentifully sprinkled with small white geodes. Although some of these contain quartz with a small proportion only of albite, more generally numerous minerals are found arranged in roughly concentric layers, suggesting several infiltrations. A dark zone rich in grains of ilmenite is frequently seen adhering to one side of a vesicle. Most of the rocks are traversed by thin wandering veins of secondary quartz and albite, and in one case (fig. 12 a, p. 504) such a vein taps several vesicles which were evidently in communication with one another at the time when they were filled.

Chemical composition.—The highest flow on Dduallt was selected for analysis as being a typical member of the series, the details being tabulated below. The composition of the 'average spilite' (the average of seven analyses) is given in a parallel column, together with the analysis of the particular rock of its kind which approaches most closely to that from Dduallt—a lava from Tayvallich.

yvallich.			
<i>y</i> 1101110-11	IV.	V.	VI.
Silica	55.75	46.01	51.31
Alumina	13.29	15.21	12.67
Ferric oxide	0.88	1.35	0.54
	8.46	8.69	7.99
Ferrous oxide	1.80	4.18	2.19
Magnesia	6.85	8.64	8.17
Lime	4.07	4.97	5.21
Soda	0.37	0.34	0.54
Potash	2.95	2.48	2:31
Water above 110°	0.20	2 10	0.04
Water below 110°	3.63	4.98	6.15
Carbon dioxide	1.86	2.21	1.92
Titanium oxide		221	102
Zirconia	trace	0.01	0.90
Phosphoric oxide	0.19	0.61	0.90
Chlorine	trace		
Sulphur	0.17	-	
Manganous oxide	0.23	0.33	0.45
Strontia	trace	_	
Barium oxide	none		
Lithia	trace		_
	100.70		
less 0 for S	0.06		
Totals	100.64	100.00	100.39

IV. Spilite, Dduallt (Merioneth), analysed by Dr. H. F. Harwood.

V. Average of seven analyses of typical spilites.

VI. Spilite, Tayvallich, analysed by Mr. E. Radley, quoted from 'The Geology of Knapdale' Mem. Geol. Surv. 1911, p. 87.

The total number of spilites analysed is lamentably small, especially in view of the controversy which has raged around the claim that these lavas should rank as a distinct rock-type. Several interesting facts are brought to light when a comparison is instituted between the new analysis and those made previously. The silica percentage is distinctly higher than usual, bringing the rock to the border-line between spilite and keratophyre. The magnesia and lime are correspondingly low, but there is no equivalent increase in the amount of alkalies. Thus, for its silica percentage, the rock is not so strongly alkaline as most other spilites. At the same time, it is interesting that the rock contains almost exactly the amounts of soda and potash found in the 'average spilite'. In respect of the low potash, the high soda and titanium contents, and the state of oxidation of the iron, as well as in other less important particulars, the rock proves to be a typical member of the spilitic suite.

The calculated mineral composition (norm) is as follows:-

	Per cent.
Quartz	. 18.3
Orthoclase	. 2.2
Albite	. 34.4
Anorthite	. 9.9
Corundum	. 2.5
Hypersthene	. 16.3
Magnetite	. 1.3
Ilmenite	. 3.5
Pyrite	. 0.3
Apatite	. 0.4
Calcite	8.2
Water	3.1

Although the Dduallt spilite contains less lime than the average, it also contains less carbon dioxide, so that, unlike most spilites, anorthite appears in the norm. The small amount of orthoclase is noteworthy, none being seen in thin sections, and it is doubtless occult. If we add the orthoclase to the albite, the calculated composition of the plagioclase is $Ab_{79}An_{21}$: in other words, it is oligoclase.

(c) The Basaltic Rocks.

Serial sections cut from the pillow-lava on Y Fron show a textural range from devitrified tachylyte through variolite to fine-grained dolerite. In mineral contents these rocks contrast strongly with the spilites described above: the plagioclase is considerably more basic, being chiefly acid labradorite, while the pale-brown augite is surprisingly fresh, in the variolites showing no trace of alteration. On the other hand, the microphenocrysts of basic plagioclase usually are completely pseudomorphed, although their forms are well preserved.

Vesicles are exceptionally rare, of perfectly spherical form, and so minute as to pass unnoticed in the hand-specimens of the rock. They are filled with calcite bordered by marginal, colourless chlorite,

and including an occasional crystal of clinozoisite.

In the variolites, both plagioclase and augite assume an accular habit, the former exhibiting the crude centric arrangement characteristic of such rocks, while the latter forms aggregates of closely packed rods interstitial to the felspar. With increasing coarseness of grain, both the variolitic texture and the rod-like habit of the augite are gradually lost, the rocks passing insensibly into fine-grained subophitic dolerites, indistinguishable from the finer parts of the gabbroid dolerites of the district. It is clear that the two sets of rocks are co-magmatic, and that the affinities of the variolites are with the dolerites, rather than with the other (spilitic) flows. But it may here be remarked that only in the freshness of its components does the variolite of Y Fron differ from some spilites, particularly those in the Upper Basic Group on Pen-y-Gader.

It is not difficult to find rocks similar in composition and textural range to those described above. In Britain they range from 2 M 2

the pre-Cambrian variolites described by Dr. E. Greenly in the Mona Complex to the Tertiary examples described by Dr. Alfred Harker, Dr. Herbert H. Thomas, and others. In particular, Dr. Harker's figures of some of the basaltic lavas of Skye and other parts of the Brito-Icelandic province are almost identical with the rocks from Y Fron.

Chemical composition.—The compact variolite from the outer part of a pillow from this flow was selected for analysis, the results of which are tabulated below, together with the analyses of a typical plateau-basalt from Skye and of Dr. R. A. Daly's average basalt, which are quoted for comparison:—

Oabato, willow 1			
	VII.	VIII.	IX.
Silica	49.38	46.61	49.06
Alumina	15.94	15.22	15.70
Ferric oxide	1.13	3.49	5.38
Ferrous oxide	7.84	7.71	6.37
	6.56	8.66	6.17
Magnesia	11.10	10.08	8.95
Lime	3.53	2.43	3.11
Soda	0.19	0.67	1.52
Potash	2.39	2.07	1 00
Water above 110	0.17	1.10	1.62
Water below 110°	0.15	trace	
Carbon dioxide	1.77	1.81	1.36
Titanium oxide	trace	n, d,	_
Zirconia	0.18	0:10	0.45
Phosphoric oxide	trace	0.10	0 40
Chlorine	0.03		
Sulphur	0.03	0.13	0.31
Manganous oxide		0.19	0.01
Strontia	none		
Barium oxide	trace	_	
Lithia	trace		
	100.52		
less 0 for S			
Totals	100.51	100.08	100.00

VII. Variolite, Craig-y-Benglog (Merioneth). Analyst, Dr. H. F. Harwood.
VIII. Basalt lava, quoted from the Skye Memoir, 1904, p. 31. Analyst, Dr. W. S. Pollard.

IX. Average basalt, quoted from R. A. Daly, 'Igneous Rocks & their Origin,' New York, 1914, p. 315.

It will be noted that a very close comparison can be made between the variolite and Daly's average basalt, particularly in respect of the amounts of silica, alumina, soda, and titanium oxide. The most striking difference is the abnormally low potash, the large amount of lime for the silica percentage, and the small quantity of ferric oxide. The marked preponderance of ferrous over ferric oxide is noteworthy, being a feature claimed by H. S. Washington as characteristic of submarine basic lavas. Notwith-

¹ Amer. Journ. Sci. ser. 4, vol. xxvii (1909) p. 148.

standing the differences noted above, the important fact that the rock is an ordinary basalt is self-evident.

The norm of the rock is as follows:—

	Per cer	ıt.
Orthoclase	1.1	
Albite	29.8	D.,,
Anorthite	27.0	Per cent.
Diopside	20.3	consisting of wollastonite 10.9 enstatite 9.4
Hypersthene		enstatite 9.4
Olivine		consisting of $\begin{cases} \text{forsterite} & 4.2 \\ \text{fayalite} & 6.9 \end{cases}$
Magnetite	1.6	tayante 6.9
Ilmenite		
Pyrite less than		
Apatite		
Calcite		
Water (total)		

The plagicalse has the composition $Ab_{51}An_{49}$, that is, acid labradorite, which is in accordance with its optical properties in the larger microlites and crystals in the doleritic portions of the flow. Neither olivine nor hypersthene is modal, the only matic mineral actually present, in addition to the accessories, being augite.

(d) The Relation of the Basalt to the Spilites.

The main purpose of the analyses was to provide exact data for the comparison of the basaltic rocks with the spilites higher in the succession.

It has been shown above that the earlier volcanic cycle of Rhobell was subaërial, that the dominant extrusive rock-type is andesite, while the associated minor intrusions are diorite-porphyries: that is, both are typical calc-alkali rocks. The calc-alkaline magma which they represent may be regarded as having resulted from crustal uplift of the area, accompanied by slight folding towards the close of the Cambrian Period. This is completely in accord with Dr. A. Harker's conception of the influence of earthmovements upon the primary differentiation of magma: orogenic movements resulting in the straining-off and migration out of a district of the alkaline portion of the magma, the calcic part remaining and becoming available for local vulcanicity.

During the interval between the earlier (Rhobell) and the later (Llandeilo) outpourings, the conditions had changed from subaërial to submarine, and the stress conditions consequent upon uplift and folding had given place to those resulting from prolonged subsidence. These changes have impressed a spilitic character upon ensuing vulcanism in many different areas, and the Llanfachreth district was no exception to the rule, although the variolites of Y Fron are difficult to fit in with the general scheme. In what relative degree the changed conditions of stress

¹ Pres. Address, Q. J. G. S. vol. lxxiii (1917-18) pp. lxix-lxx.

and of outpouring were respectively responsible for the conversion of andesite into spilite is difficult to estimate; but the insufficiency of submarine conditions alone to effect this is proved by the very close association of normal olivine-basalt with an alkali-rich modification in at least one other area (Derbyshire).1 In the present case there is no evidence of any change in the conditions of eruption between the earliest and the latest flows: both were submarine, both developed pillow-structure, both were chilled to a marginal glass, but otherwise they differ in most particulars. It follows, therefore, that there must have been pre-extrusion differences between the two rocks when in the molten condition. It is unlikely that they occupied different magma-basins. they were co-occupants of the same basin, the spilitic portion must (by reason of its lower specific gravity) have occupied the higher parts, the basaltic portion the basement. It may be recalled that Dr. R. A. Daly has pictured the relationship of spilite to basalt to be that of alkaline scum to calcic liquid,2 and one is bound to admit a measure of truth in the suggestion, although in the present case there appears to have been an excess of scum over liquid, while in the Cader Idris area the magma was all seum -at least in so far as the portions actually visible are concerned. East of Rhobell a small residuum of basaltic magma persisted in unmodified form, but was exhausted in a single flow.

A full discussion of the causes of the differences between the lavas of Arenig, Cader Idris, and Rhobell would be difficult, as there are no recent petrological accounts of the first two districts, and the brief descriptions now available were written before the important papers dealing with the spilitic rocks were published. A brief examination of Moel Llyfnant has convinced me that the differences are real, and hence one suspects differences in the conditions of eruption at the various centres concerned. It is significant that the total thickness of the Ordovician up to the base of the Bala mudstones is approximately twice as much at Cader Idris as at Arenig Mountain, and that not only does the number of intercalated sedimentary rocks increase from north to south, but the shale-bands themselves thicken considerably in the same direction. The Cader centre was definitely submarine, and the surrounding tract was one of relative depression. On the other hand, the Arenig volcano, although originating as a submarine cone, at a later stage built itself up above sea-level, and henceforth was subaërial. If we may judge from the inferior thicknesses of most divisions, the surrounding tract was one of relative uplift. These differences are adequate to account for the observed petrological differences. The Rhobell area lies midway between these two centres, at the fulcrum as it were, and here there is mixing of the two kinds of magma-the spilitic with the calc-alkaline type.

H. C. Sargent, Q. J. G. S. vol. lxxiii (1917–18) p. 11.
 'Igneous Rooks & their Origin' 1914, p. 339.

VIII. THE UPPER ACID VOLCANIC GROUP.

The slates above the Llandeilian Volcanic Series are very different in appearance from the underlying mudstones, being tough, and leaden grey in colour. Their rapid variation in thickness is significant, and appears to be an original feature: the base of the shale rests upon the upper surface of the highest flow of spilite, the magma of this kind being exhausted by this outpouring. At the top of the band there is a gradual incoming of ash mixed with broken felspar-crystals, and there is evidently a normal passage from the marine sediment into the volcanic rock.

On account of its influence upon the topography and scenery of the district, the Upper Acid Group is important. The outcrop, which is easily traceable from north to south of the area, is marked by prominent hills over 2000 feet high, dominated only by Rhobell Fawr itself. The rocks are best exposed on the long ridge of Dduallt, Foel Ddu, and the hills overlooking Drws-y-Nant, where their outcrop is abruptly truncated by the Bala Fault. At the base of the series on Dduallt, a typical nodular rhvolite occurs in close association with a beautiful flow-banded lava. The rocks above are rather monotonous in type, being largely of pyroclastic origin, but including coarse breccias which are probably flow-brecciated lavas. The rocks are very siliceous, which accounts for their extreme toughness; but they are not everywhere silicified to the same extent. A series of specimens collected from different points shows a progressive silicification, the one extreme type being a dark slaty ash, the other possessing many of the physical properties of flint. Although the lower part of the series is distinctly bedded, the rocks become less well stratified upwards, but there are indications that the steep eastward dip is maintained to the top. The eastern side of Dduallt is precipitous, and is the most striking topographical feature in the neighbourhood. In this respect it resembles the formidable dip-slope of the Arans, the same type of rock forming the feature in both cases. The contrast between the precipices of Dduallt and the swampy plain (occupied by the Bala mudstones) stretching away from its foot is most impressive.

One gathers from earlier accounts that the officers of the Geological Survey regarded the 'felstone' of Dduallt as a lithological unit, although they appear to have been divided as to its extrusive or intrusive nature. It is assuredly a volcanic series some 1100 feet thick, and it certainly includes ashes and lavas, though whether any part of it is intrusive is a matter for future research. The relation of the columnar felsite at the southern end of Dduallt to the rocks against which it abuts is somewhat

puzzling, and the felsite may well prove to be intrusive.

As noted above, siliceous ash makes its appearance at about the middle of the spilitic series, so that, although separated by a short period of normal sedimentation, the two may be regarded as

portions of one great volcanic episode, during which there was a general acidification of the magma, as shown by the character of its extrusive products. In the district here described, as in those around Cader Idris, the Arans, and Arenig, the final products were 'rhyolitic'. Thus ended abruptly the Ordovician igneous cycle, the products of which achieved a greater diversity in the Llanfachreth district than anywhere else in North Wales.

IX. The 'Bala Mudstones' and the Age of the Volcanic Rocks.

The shales and mudstones above the volcanic rocks have not been examined in detail; indeed, little of them is to be seen in the district under survey. Search along the foot of Dduallt reveals the presence of crushed shales in contact with the volcanic rocks at a few points only—there is no exposure worthy of the name. In the moor on the east, which is impassable except in very dry summers, they are buried deep beneath the peat. Fossils have not been obtained from the main spread of the sedimentary rocks, but that the lowest part of the Bala Mudstones is of Nemagraptus-gracilis age is suggested by the results of recent investigations elsewhere. From shales occurring between the highest volcanic rocks of Arenig and the Derfel Limestone, Miss G. L. Elles obtained a suite of fossils indicative of a horizon in the Upper Glenkiln, and including *Dicellograptus sextans* and *Nemagraptus*. The lowest beds of the Tal-y-Llyn Mudstones, occupying an analogous position with respect to the volcanics of Cader Idris, yielded Amplexograptus arctus and Glyptograptus teretiusculus var. euglyphus,2 while more recently G. teretiusculus and other graptolites of an indeterminate nature were collected from the same horizon in the Corris district. It is, therefore, probable that volcanic activity ceased in the three areas at approximately the same time. In the tract east of Rhobell the main spread of volcanic rocks lies in the gracilis zone: that is, at the same horizon as at Llanwrtyd Wells.3

Any attempt to correlate accurately the various volcanic horizons of the three areas must be incomplete, as the faunal evidence is inconclusive. In addition, it would be unreasonable to insist upon a strict chronological correlation, as the rocks are lithologically so dissimilar, and were erupted from different centres which may not have been in eruption simultaneously.

The I ower Acid Group is restricted to Southern Merioneth, reaching the maximum development in the foot-hills of Cader Idris and dying but a short distance north of Moel Offrwm.

The Lower Basic Group of Cader and their equivalents, the Platy Ashes and Agglomerate of Arenig, are definitely of post-

 $^{^{1}}$ 'The Bala Country: its Structure & Rock-Succession' Q. J. G. S. vol. lxxviii (1922) p. 144.

A. H. Cox & A. K. Wells, Rep. Brit. Assoc. (Manchester) 1915, p. 425.
 L. D. Stamp & S. W. Wooldridge, Q. J. G. S. vol. lxxix (1923) p. 32.

bifidus age, though to how great an extent of that age is still uncertain, pending the discovery in the overlying shale-bands of definite zonal forms. It is possible that the Llyn-y-Gader Slates, including the pisolitic iron-ore, are correlative with the Daerfawr Shales of Arenig and with the shales containing the Nemagraptus-gracilis fauna at Rhobell. The Platy Ashes and Agglomerate are therefore unrepresented by volcanic rocks in the northern half of the area here described. It is possible that they are faulted out; but, in view of the marked thinning of these beds in a southward direction at Arenig, it is more probable that they have thinned out. It is only in the drift-covered southern portion of the area here described that their distinctive lithology (of Cefn-Hir Ashes type) reappears. The small thickness of beds between the bifidus and the gracilis zones suggests a break at the base of the latter.

Throughout this account it has been taken for granted that the main volcanic group is to be correlated with the Upper Basic Group of Cader, and the Rhyolitic Group with the Upper Acid Group, while the intervening sediments are the equivalents of the Llyn Cau Mudstones. The lithological resemblances are too close to be merely accidental, and the meagre palæontological evidence supports this correlation.

X. THE BASIC INTRUSIONS.

(a) Field Relations.

The majority of the intrusions other than those belonging to the Rhobell Volcanic Group are of doleritic composition. With only one or two exceptions they are sill-like in habit, and were intruded in the slates underlying the Rhobell Series; immediately above the volcanic mass of Rhobell, and at various levels in the Basement Group; and in the higher (Llandeilo) volcanic series.

In most cases their relationship to the intruded rocks is quite clear, and there is little difficulty in determining the forms of the intrusions. The most interesting are those which occur at or near the horizon of the Garth Grit. In the earlier accounts of Rhobell Fawr certain of the dolerites were located; but their relationship to the bedded rocks was misread, as they are shown on the published sections as more or less vertical masses rising through the volcanic pile in the manner in which contemporaneous intrusions into a volcanic cone are supposed to behave. Mapping of the summit of Rhobell Fawr has shown that the dolerites form an almost unbroken ring around the mountain (see map, fig. 7, p. 497); while at more than one point north of the summit the underlying volcanic rocks have been excavated by denudation, leaving a projecting ledge of dolerite which is seen to be dipping concordantly with the overlying flags. Both on the north where the intrusion disappears beneath the flags, and on the south where it re-emerges, the extent of the contact-alteration is considerable, while minor irregularities in the upper surface of the intrusion cause small 'inliers' of dolerite to rise through the film of altered flags, and small 'outliers' of flags to occur on the dolerite near the junction. Thus it is evident that the intrusions are sills (or possibly one sill cut up by subsequent faulting), inclined at a small angle to the surface of the ground, and dipping almost concordantly with the bedding of the Basement Group. A certain amount of transgression can be demonstrated in quite small exposures, the sill being sometimes at the plane of unconformity, but elsewhere cutting into the Basement Flags. It cuts down into the underlying volcanic rocks at one point, and the section is a very instructive one. The intrusion north-west of the summit-cairn undulates somewhat, and at one point bends down into the ashes: it at once loses its sheet-like form, and tails out in a maze of irregular veins. The only other doleriteintrusion in the volcanic rocks is found about half-way up the eastern side of the mountain, near the fine hornblendic tuffs already mentioned. This is one of the few spots where the bedding of ashes and agglomerates is pronounced. The intrusion is identical in composition with the sills at the summit, and is itself cut by thin aplite-veins. That these are the only two dolerites in the whole of the Rhobell mass testifies to the homogeneity of the volcanic rocks, in respect of resistance offered to the passage of even basaltic magma. This selection of suitable country-rock has, of course, been commented upon more than once.1

It can scarcely be doubted that the sills near the summit of Moel Cors-y-Garnedd were originally connected with those on Rhobell Fawr. They occur at exactly the same horizon, and petrographically they are identical. Minor faulting has been more active in the former locality in chopping the sheet into isolated patches, just as a somewhat more important displacement has separated the dolerite of Rhobell from that of Moel Cors-v-Garnedd. The gabbroid dolerite which is prominent on the southern and eastern flanks of Moel Offrwm rests on the Garth Grit in the Deer Park, and thence cuts up through the Basement flags into the massive ashes of the Basement Group. Further, it has been shown above, that, south and west of Dolgelley, the same massive coarse-grained dolerite occurs again in sill-like form, and again at the same horizon (a short distance up in the Basement flags). It is an interesting and suggestive fact that the map of Arenig Fawr and Moel Llyfnant shows exactly the same feature: the Garth Grit and Extensus Flags (= Basement Group) are almost everywhere closely associated with doleritic intrusions, which, if we judge from the manner in which one of them encircles Moel Llyfnant, must be sills. Now, these intrusions are all sills, and in the Arenig and Rhobell districts the dolerite outcrops are almost continuous. In view of these facts, one can hardly

¹ A. Harker, 'The Tertiary Igneous Rocks of Skye' Mem. Geol. Surv. 1904, p. 293.

² W. G. Fearnsides, 'The Geology of Arenig Fawr & Moel Llyfnant' Q. J. G. S. vol. lxi (1905) pl. xli,

resist the conclusion that, at least in their respective districts, the sills are portions of one extensive sheet, derived from one common

magmatic source, and intruded at the same time.

Neither at Arenig nor in the neighbourhood of Rhobell are there any dykes that might have served as feeders to the sills, and, instead of regarding them as isolated intrusions bereft of any visible connexion with a deep-seated source, it seems more reasonable to look upon them as having been originally connected in a horizontal sense. The sheets are not absolutely continuous: faulting and denudation have caused many breaks; but, in addition, folds already in existence at the time of intrusion, and differences in the nature of the country-rock separated by the plane of unconformity caused the local failure of the magma to spread evenly, so that there are gaps in the outcrop. Now, the intrusions, although everywhere at approximately the same stratigraphical horizon, occur at very different levels. (approximately) 2300 feet on Rhobell Fawr, 1500 feet on Moel Cors-y-Garnedd, 900 feet on Moel Offrwm, and 600 feet near Dolgelley. This is partly the result of the south-eastward dip of the sill, which thus follows the sheet-dip of the Basement Group, but is in part the result of faulting. Unless one be prepared to admit that the magma was sufficiently selective during the act of intrusion to search out this horizon at these various levels and persistently flood it, while neglecting numberless other planes apparently equally suitable, one must conclude that the intrusion antedated both folding and faulting. The second alternative is surely far more likely. A plane of unconformity would in any case be a plane of weakness, and one likely to be invaded by concordant sheets during a subsequent phase of minor intrusions. In this case however, although the sheet is always near the plane, it is seldom intruded actually along it: that is, the mere presence of the plane of weakness was only incidental in determining the level at which the magma was injected, which it may be surmised was determined principally by hydrostatic conditions. Prof. A. H. Cox reached a similar conclusion with reference to sills in the Basement Group near Arthog.

None of the transgressive sills in the Basic Volcanic Group attains the thickness of the gabbroid dolerites lower in the succession. They are more frequently vesicular, they are naturally of finer grain, and in many cases have acquired during cooling a very regular jointing. One point of interest is the frequency with which the contacts are well exposed, particularly on the southern slope of Craig-y-Benglog. The main intrusion on this hill approximates to the form of a flattened cedar-tree laccolite, as it has invaded the ashes along several bedding-planes. Although these ashes are comparatively well bedded, the dolerite contacts are unusually irregular, and convey the impression that the ashes have been ploughed up by the dolerite and thoroughly mixed with it, making it difficult to decide upon the line between intrusion and ash. This type of junction is difficult to explain (as the

intrusions are only a few feet thick) if the act of intrusion was subsequent to the consolidation of the country-rocks. It would be the natural result of the intrusion of fluid magma into unconsolidated submarine beds of ash. This manner of injection would account for the vesicularity of the dolerites and their general similarity to the basic flows of the district. As already noted, it is difficult to find conclusive evidence of the intrusive or extrusive origin of many of the basic rocks of this district—a difficulty experienced by other workers in similar rocks elsewhere.

(b) Petrology.

Although there is little variation in the minerals building these rocks, several distinct types differing in textural details can be

recognized.

The coarsest-grained intrusive rock in the district is the Nant-Gôch gabbroid-dolerite. Part of this and other intrusions are quite coarse enough to justify the application of the term 'gabbro'. No separate description is necessary, however, as they do not differ essentially (except in size of grain) from the gabbroid dolerites, which are of simple mineral composition, consisting of augite, plagioclase, ilmenite, and their alteration-products. Neither olivine nor orthorhombic pyroxene has been discovered in any of the slides examined. The plagioclase in the freshest rocks is in part water-clear, and surprisingly free from those alteration-products usually so prominent in Welsh dolerites. It is strongly zoned, the innermost portions having the composition of medium labradorite, while the outer zones may be as acid as oligoclase.

The augite is the common, pale-brown type with, however, a patchy distribution of colour, giving the appearance of a crude zoning. The inner parts of the crystals are often colourless, while a brown tint with a trace of mauve and a suspicion of pleochroism

appears in the outer parts, suggesting titan-augite.

The ilmenite occurs in the usual bizarre skeletal forms, a few of which are regular enough to suggest trigonal symmetry.

The alteration of the essential minerals.—The commonest alteration-product is pale-green chlorite, yielding the normal rich blue and brown interference-tints of penninite. The brown polarizing variety forms minute spherulitic aggregates, embedded in a fibrous matrix of the blue variety. Numberless sharply pointed actinolite-crystals penetrate the chlorite, while a zone of such crystals invariably separates the latter from the unaltered augite. In the dolerites, as in the basic lavas, the chlorite has invaded the plagioclase-crystals along the cleavages, thence spreading through their substance, and in many cases effecting complete replacement. On the other hand, in fresh material, it is curious how seldom one can prove a patch of chlorite to have been derived from the destruction of the augite. In the vast majority of cases, vestiges of plagioclase embedded

in or surrounding the chlorite prove derivation from the former mineral, while frequently such patches abut against a well-formed face of an augite-crystal. It is quite evident that much of the chlorite, if not actually primary, is the product of a juvenile reaction. Its mode of occurrence is strongly reminiscent of that of the analcite in teschenites and allied rocks.

The breaking-down of the two chief minerals has resulted in the formation of zoisite, clinozoisite, and less epidote. Very rarely, reaction between augite-crystals and residual sodic liquids has resulted in the formation of small agirine-augites, or of brown or green soda-amphibole.

Although the normal felspar of these rocks is a somewhat basic

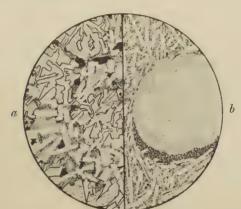


Fig. 13.—Modifications of dolerite, \times 20.

a - Chilled dolerite, Moel Cors-y-Garnedd. Irregular areas of cleaved angite, intergrown with plagicelase, embedded in a ground-mass of felspar and iron-ores in an irresolvable base.

b=Spilitic dolerite, margin of the Ystum-Gwadnaeth intrusion. Microlitic albite in pronged and curved forms in an irresolvable base. Vesicle with an infilling of chlorite (stippled) and calcite (clear), with a dark border rich in ilmenite.

plagicelase, the effects of albitization may be detected. The alteration in some cases has produced only insignificant changes in composition, in others it has been complete, pure albite being now the sole felspar present. It is noteworthy that this contrast may be noted in different parts of the same intrusion. Thus one slide cut from the Ystum-Gwadnaeth sill contains albite only, but another contains labradorite. Both specimens are equally coarse in texture, and in the former there is actually less chlorite and epidote than in any other dolerite examined from this district. One is cautious, however, of using these facts as evidence of a

general increase of basicity from the margins inwards, although this has been shown to be the case with similar rocks elsewhere.¹

Microscopic structure.—The normal structure of the gabbroid dolerites is ophitic, but this is by no means invariably developed: even in the same sill, a highly developed ophitic structure may give place in quite a short distance to one in which the augite tends to idiomorphism, or the rock may take on a gabbroid aspect, neither of the chief minerals being particularly well formed. A fourth and widely distributed variant approaches closely to the normal ophitic type, but the augite, which embraces very narrow plagioclase-laths (the arrangement of which conveys more than a suggestion of centric structure), occurs in large crystals embedded in a matrix essentially felspathic. The plagioclases in this matrix are much larger than those enclosed in the augites. This is evidently the 'ophimottling' of Dr. Herbert H. Thomas.²

Marginal modifications.—In two cases only (the Ystum-Gwadnaeth and Drws-Melau sills) the marginal rocks bear a strong resemblance to the normal spilites of the district (fig. 13 b, p. 523). The rock is obviously much altered, some portions of it being completely calcified: the outlines of the felspar-laths are, however, retained. There is no doubt that, if the relations of these rocks were unknown, they would pass as fairly representative spilites. They are demonstrably the outer portions of sills, the one intruded at a high level in the Basement Group, and the other along the plane of unconformity beneath the latter: that is, at horizons far below that at which the spilites occur. In the course of a foot or two this spilitic modification passes in both cases into normal gabbroid dolerite, which has supplied some of the freshest material examined.³

The normal chilled phase is relatively rich in augite, and as a rule does not exhibit any structural peculiarities. The common type is an augite-rich 'microphitie' dolerite.

(c) The Dolerite-Aplites.

The gabbroid dolerites occurring both below and above the Rhobell volcanic pile possess one other feature in common: they contain numerous aplite-veins, which have not been found in the intrusions at higher levels. The aplites are finer in grain, paler in colour, and tougher than the parent-rocks, from which they protrude as prominent ribs. While some of them behave as thin sills, up to about 6 inches in thickness, others are merely irregular wandering veins. They are restricted to the doleritic outcrops—

¹ H. Williams, 'The Igneous Rocks of the Capel Curig District (North Wales)' Proc. Liverpool Geol. Soc. vol. xiii (1922) p. 193.

² 'Tertiary & Post-Tertiary Rocks of Mull' Mem. Geol. Surv. 1924, p. 138.

³ Cf. H. Williams, op. supra cit. p. 194.

none has been found as an individual intrusion in the country-rock.

Under the microscope, the aplites are seen to be felspathic rocks deficient in coloured minerals. The chief component is idiomorphic felspar in short rectangular to nearly square sections, embedded in a base which is also largely felspathic, though densely charged with minute opaque inclusions (probably in part ilmenite-dust and in part kaolin). The idiomorphic felspar is albite, showing, in addition to the usual types of twinning, some of cruciform habit and others twinned in two directions at right angles, giving diametral twins which, by increase in the number

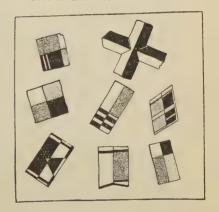
Fig. 14.



a=Porphyritic dolerite, south of Craig-y-Benglog, in *Dicranograptus* Shales. Albite enclosing epidote and chlorite. Interstitial chlorite with rosettes of zoisite. Augite (stippled) in subidiomorphic crystals and ophitic patches. × 20.

x 20.
 b=Dolerite-aplite, Rhobell Fawr summit.
 Albite in rectangular sections, elongated hornblendes, and ilmenite in a base of decomposed felspar. x 20.

Fig. 15.—Twins of plagioclase in dolerite-aplite, summit of Rhobell Fawr. × 20.



of 'windows', pass gradually into chequer-albite (fig. 15). The crystals are fresh, except for a thin marginal zone of inclusions similar to those in the felspar which constitutes the base. This is presumably orthoclase, together with a little chlorite and some quartz. In most specimens examined the coloured mineral is hornblende in elongated ragged flakes which pay no heed to the boundaries of the plagioclase: one individual of hornblende may often be seen to penetrate several of plagioclase. In other aplites the only coloured mineral is fresh augite, pale brown to colourless, occurring in the small crystals of earlier formation than the felspar,

and often twinned on {100}. Brown translucent ilmenite in well-formed crystals and minute apatites are constant accessories.

With reference to nomenclature, there seems to be no need to attempt to improve upon the name aplite. These rocks are dolerite-aplites exactly comparable in genesis, mode of occurrence, and texture, with such firmly established types as granite-aplite and syenite-aplite.

(d) The Age of the Basic Intrusions.

Doleritic intrusions resembling those described above occur in most of those parts of North Wales that have been recently resurveyed. It is evident, however, that agreement as to their age has not been reached. As urged in the Dolgelley paper, the fact that dolerites occur at every horizon up to the Upper Basic Series, but not above, is strong evidence for their Ordovician age. In the Rhobell district there is little new positive evidence that can be adduced to support this claim. The intrusions have obviously, as a whole, antedated the main folding and faulting, which was presumably Caledonian. At several points on Rhobell Fawr the flags of the Basement Series are sheared parallel to the main cleavage direction of the district. As the dolerite-contacts are approached, the gaping fissures become fewer, less prominent, and finally disappear altogether. This fact can be explained in two ways:

- (i) intrusion preceded cleavage, thus hardening the rocks near the contacts sufficiently to resist the cleavage stresses;
- (ii) intrusion followed cleavage of the shales, the resulting contact-action obliterating bedding and cleavage.

The first suggestion could be adopted if it were supported by additional evidence. Now, although (as a general rule) the dolerites are singularly massive rocks, some are themselves roughly cleaved: for example, parts of the thick columnar sill east of the gorge through the Cyfyng-y-Benglog. The effect, however, is rarely, if ever, so marked as with the rocks of the Rhobell Group. It must be acknowledged that, if the dolerites are pre-Caledonian, both they and the Rhobell rocks should show the effects of earthmovement to a comparable degree, as both have gone through the same revolutions. (Actually the Rhobell rocks experienced, in addition to the Caledonian, Armorican, and Alpine revolutions, a certain amount of movement in pre-Garth Grit times, but the effect must have been slight.)

It may be pointed out that, although in Snowdonia the lavas are essentially rhyolitic, in the Arenig-Mountain district they are andesitic, in the Rhobell district basaltic-spilitic, and in the Cader-Idris range dominantly spilitic: in all these areas the common intrusive type is dolerite, apparently differing very slightly from place to place. It may with reason be claimed that these basic intrusions constitute a regional series of sills. In the Tertiary

¹ Q. J. G. S. vol. lxxvi (1920-21) p. 304.

cycle distinctive extrusive and intrusive rock-types were produced locally at the eruptive centres. The intrusive 'andesites', like those exposed in the great quarries near Arenig Railway-station. are of the same nature. In the Rhobell area the 'local' pass gradually into the 'regional' series, the former including the spilitic dolerites, which differ from the regional gabbroid dolerites in their more pronounced alkalinity. Thus the lowest intrusions (in the Upper Cambrian) are massive and gabbroid in texture; at higher levels they decrease in size, they become of finer grain and vesicular, approximating in appearance and composition to the spilites. There is no definite evidence to prove that the true dolerites were intruded at a date appreciably later than those with spilitic affinities. On the other hand, a spilitic marginal phase is developed in some of the most gabbroid sills, while the finergrained portions are indistinguishable from the coarser parts of the flows, even in respect of petrographical minutiæ. The application of more exact methods emphasizes the similarity: Rosiwal analyses of the Ystum Gwadnaeth dolerite (being one of the freshest) and of the doleritic portion of the Craig-y-Benglog flow show the rocks to be almost identical in mineral composition. While acknowledging that petrographical similarity is an unsafe test for community of origin, I believe that the dolerites belong to one phase of minor intrusions, and that they are more likely to have been part of the Ordovician cycle than any other. If this be not the case, one may well enquire as to the whereabouts of the Ordovician minor intrusions.

XI. STRUCTURE.

As a consequence of the situation of the district here described at the south-eastern 'corner' of the Harlech Dome, the east-and-west strike of the Arthog-Dolgelley belt gives place in its southern part to a north-east-and-south-west trend, which farther north swings round until the outcrops are aligned north and south, this direction being maintained with little variation for several miles into the Arenig-Moel Llyfnant country.

The dominant north-and-south folds responsible for the marked changes of strike of the Cambrian rocks of the Dome are paralleled in the Rhobell area, their most notable effects being produced in the east and beyond the boundary of the appended map (Pl. XXXII). In the mapped area the dominant structural

lines are

(i) the synclinal axis through Rhobell;

(ii) the anticlinal axis in the slate-tract east of the mountain; and

(iii) the synclinal axis near the eastern border of the map.

There are no important folds between the synclinal axis passing near the summit of Y Garn (2 miles west of Llanfachreth) and the western border of the Rhobell mass. Thus the Lingula Flags dip steadily away from the centre of the Dome at increasingly steep angles, approaching a vertical attitude near the western margin of the volcanic pile. There are local inversions, as may

be seen on the Precipice Walk and at many points in Bwlch

With regard to the syncline which includes the Rhobell mass,

SO FFI 2=Rhobell Volcanic Group. 3=Basement Group. 4=Shale Group (zones of D. bifidus: 7=Upper Acid Volcanic Group. D=Dolerite. Wenallt, A Fig. 16.—Section from the lower slopes of Rhobell Faur to Wenalli. Horizontal and vertical scale: 3 inches = 1 mile. Volcanic Group, with slate-band 6. Fron. Defaid. 5 = Main 1=Upper Cambrian. gracilis).

the inward dip of the slates bordering the latter can be demonstrated at many places, but it is improbable that the structure was synclinal when the volcanic centre was here It is far first established. more likely to have been located above an anticline, in which case the present structure can be explained, either by collapse of the arch supporting the eruptive mass, or by subsequent folding. Either explanation is competent to explain the present disposition of the beds, but the former is the more attractive. Collapse of the supporting fold is a different conception from that favoured by earlier writers —that the erupted mass 'sank through the shattered Lingula Flags' (p. 491). Post-Ordovician folding is proved by the fact that the synclinal structure of the slates bordering and underlying the volcanic pile is reflected in the Basement Beds at its summit. these rocks, however, the dips are much more gentle (fig. 7, p. 497, & fig. 10, p. 501).

The anticline east of the mountain brings up the Ffestiniog Beds at the foot of Moel Cors-y-Garnedd and again farther north in the moor south-west of Dduallt, and so near the Ordovician outcrop that there must be a strike-fault on its eastern side.

The Bala Mudstones in the

north-east of the map occupy the centre of a syncline, the volcanic rocks rising again to the surface farther east. In the south the fold has broken along its trough, throwing eastward-dipping crystal tuffs against westward-dipping ashes of the Upper Acid Volcanic Group

Within the major folds are smaller ones, usually trending in the same direction. The smallest of these are the sharp compressional folds occurring in the neighbourhood of strike-faults (probably reversed) which affect the *Lingula* Flags west of Rhobell. Only slightly larger are the gentle symmetrical rolls in the same rocks north of Rhobell, well exposed in sections on the flanks of the Mawddach valley. In the bed of the river itself, frequent changes in the amount and direction of dip bear ample testimony to the same folding along north-and-south axes.

In the same category are the north-east-and-south-west folds, which amount to little more than ripples, that can be observed almost anywhere in the Basement Group. They can be most conveniently studied in the outliers of Rhobell Fawr and Moel-y-Garnedd (see figs. 8, 9, & 10, pp. 498, 500, & 501). Rather more important is the shallow fold passing through Moel Offrwm. This is a flat-bottomed syncline pitching southwards, in which direction it dies out. In the neighbourhood of Blaenau, north-east-and-south-west minor folding has produced complications in the outcrop of the Basement Group, and an inlier of fossiliferous Tremadoc Slates.

With regard to the age of the folding, reasons have already been given for believing that north-and-south folding was initiated before the post-Tremadoc interval. But it is obvious that movement along similar lines must have taken place subsequently, probably at more than one period. During the Caledonian revolution the folding was accentuated, while change in the conditions of stress altered the trend of the folds to north-east and south-west. The Rhobell mass acted as a resistant knot—as it were, an outlier of the hard rocks of the Harlech Dome—against which the folds were buckled; as a consequence of this the foldaxes, like the strike of the beds and the cleavage-strike, tend to swing round, as already noted.

The district is a much faulted one, the dislocations trending in several directions, of which three are important. These are north and south, north-east and south-west, and north-west and southeast. On the 1-inch Geological Survey map of North Wales (Harlech, Sheet 37) several important faults with a north-and-south trend are traced, some occurring in the district here described. The possibility of the western boundary of the Rhobell mass being such a fault has already been discussed (p. 472). The eastern side of Dduallt is also shown as a fault on the older maps. No evidence of movement, however, is now available, although it is probable that movement has taken place along the plane separating two rocks of such different character. Further, the change in dip of the slates is too sudden to be due to folding alone. It may be remarked that, although in the vicinity of Arenig the mudstones have been thrust over the volcanic rocks, the junction

¹ G. L. Elles, Q. J. G. S. vol. lxxviii (1922) p. 160.

between the same two rock-groups, forming just as imposing a feature south of Cader Idris, is a normal unfaulted one.

The north-east and south-west faults, which are the dominant structural lines in the adjacent area around Bala Lake, are also important in the Rhobell district. In the extreme south-east the famous Bala Fault breaches the Ordovician outcrop, and causes a considerable north-eastward shift of the rocks on its southern side. Near Drws-y-Nant the throw is so great that what are practically the highest volcanic rocks in the neighbourhood are thrown against low levels in the Lingula Flags. The valley of the Wnion has been excavated along the fault, and provides the highway to the west coast. A branch dislocation, long known as the Dolgelley Fault, joins the main line of movement near Drws-y-Nant. For some distance it cannot be followed, owing to the drift-covered nature of the ground; but, from near Castell-y-Graig to near Dolgelley town, it can be easily traced on account of the deep notch along its course. Near the former place it forms a gash striking obliquely into the valley of the Wnion, and permitting an uninterrupted view of Dolgellev; while the feature is continued as the hollow followed by the Old Towyn Road, and gradually dies out westwards. But, despite the ease with which the feature can be traced, in the middle part of its course the throw appears to be inconsiderable, though it increases both north-eastwards and south-westwards. Parallel displacements have been encountered at intervals over the whole district. They maintain a fairly constant direction, despite changes of strike. Thus, while they behave as strike-faults in the south. they are dip-faults farther north, notching the strike-features of the Ordovician rocks, as (for example) on Dduallt. From a study of the map, the alignment of features in the same (northeast and south-west) direction suggests the presence of other faults not shown as such on the map. The south-eastern margin of the Rhobell mass between Craig-Fâch and Moel Cors-y-Garnedd is of this nature, suggesting that the proven faults on the latter may continue across the slate hollow, connecting with the aligned fault which truncates the outcrop of the Upper Acid Group on the south, shifting these rocks eastwards to the longitude of Foel Ddu. There is no doubt that the faults shown on the map fall short of the number actually present. Where the conditions are particularly favourable for observation, as on the summit of Moel Cors-y-Garnedd, they prove to be numerous, although throwing only a few feet (fig. 11, p. 504).

With regard to the north-west and south-east faults, one of the most important is that forming the southern boundary of the Rhobell mass (p. 474). That which gashes the eastern side of

¹ W. J. Pugh, 'The Geology of the District around Corris & Aberllefenni' Q. J. G. S. vol. lxxix (1923) p. 515.

the mountain, and, passing near the summit, throws Basement-Group deposits against the volcanic rocks, may continue across the crest of the mountain. The valley of the Afon Geirw is aligned with it, and, from a distance (as on Moel Llyfnant), it appears to cut the mountain in two.

The influence of the faulting upon the topography is evident from the map. There is scarcely a river in the district that is not guided in some part of its course by a fault-line. Such a line of weakness has been sought out by the many sluggish tributaries of the Mawddach, which, after meandering aimlessly over the sea of peat in the north-east of the area, unite at the point where the Upper Acid Group plunges beneath the Bala Mudstones, and the united stream, as a turbulent, swift-flowing mountain-torrent cuts straight through the Ordovician outcrop. Almost exactly parallel is the valley of the tributary stream, the Afon Cwm Hesgen, farther north, which was also initiated along a parallel fault-line. Similarly, the Afon Wen, after flowing for some distance through a wide valley between Rhobell and Moel Hafod Owen, turns towards the Mawddach; but, instead of flowing across the low col west of Dolvdd, it suddenly bends southwards into the precipitously-walled, V-shaped valley which is one of the most striking physical features of the area. is continued south-westwards as the magnificent Ganllwyd valley, and northwards as a small (though distinct) notch trenching the flank of Moel Hafod Owen. This is certainly a fault feature, the continuation of the Derwas Fault of the Dolgelley district.1

The cleavage.—Some of the cleavage-strikes observed are indicated on the map (Pl. XXXII), and serve to demonstrate that they swing round with the changing strike of the rocks themselves from south-west-and-north-east in the southern part of the area to north-and-south in the north. The cleavage-dip is usually at a steep angle, averaging 70°, in towards the Harlech Dome. In the centre of the area, however, in the Llanvirn and higher beds, the cleavage dips equally steeply eastwards. This direction of cleavage-dip is maintained up to the eastern boundary of the map, so that the outcrop of the Llanvirn Shales coincides with a 'cleavage anticline'.

XII. SUMMARY AND CONCLUSIONS.

The area described comprises some 30 square miles centred about the mountain-mass of Rhobell Fawr, in Southern Merioneth. The succession ranges from low down in the *Lingula* Flags to the Bala Mudstones.

The Cambrian rocks do not differ essentially from their deveopment in the Arthog-Dolgelley and Arenig Mountain areas,

¹ A. H. Cox & A. K. Wells, Q. J. G. S. vol. lxxvi (1920-21) fig. 7 & p. 310.

although the Tremadoc Beds apparently are less completely deve-

loped, not extending far above the Dictyonema Band.

The district differs from others bordering the Harlech Dome in the development of an igneous cycle above the Tremadoc, but below what is, in adjacent areas, the local base of the Ordovician. The Rhobell Volcanic Group comprises an extrusive phase, the products of which were essentially andesitic, and a phase of minor intrusion when sills of diorite-porphyry were injected into the rocks underlying the Tremadocian, and sills and dykes of the same type penetrated the lower rocks of the Harlech Dome. The centre of eruption, of which Rhobell is the denuded basal wreck, was subaërial. A period of non-deposition was terminated by the transgression of the Arenig sea, and the rocks of the Basement Group (Garth Grit, Extensus Flags, and Calymene Ash) were deposited, these rocks being derived from the denudation of a volcanic centre lying east of Rhobell.

In the succeeding shaly series, fossils from horizons immediately underlying the main volcanic series belong to the zone of Nemagraptus gracilis, while at lower levels the tuning-fork graptolites

of Lower Llanvirn type occur.

The main Volcanic Group, although largely pyroclastic, includes flows of basalt (variolitic to doleritic in texture) and spilite. Both have developed pillow-structure, and the series which includes a

few thin shale-bands was entirely submarine.

Grev unfossiliferous slates, the equivalents of the Llvn Cau Mudstones of Cader Idris, separate the basic volcanic group from the succeeding Upper Acid Volcanic Group. These are largely fragmental keratophyres and quartz-keratophyres, the highest of which plunges down beneath the Bala Mudstones. Basic sills are common at various horizons between the Ffestiniog Beds and the Upper Acid Group. The rocks range from gabbroid dolerites with labradorite, through normal ophitic and subophitic types, to porphyritic and spilitic types indistinguishable from the basic flows. They are believed to represent the phase of minor intrusions connected with the main volcanic cycle.

The area is situated at the south-eastern 'corner' of the Harlech Dome, and as a consequence the strike changes from nearly east and-west in the south to north-and-south in the northern part. Folding along north-and-south axes is dominant, but the folds are somewhat buckled against the Rhobell mass. Small north-and-south and north-east-and-south-west folds are common throughout the district. The area is much faulted, the dominant series trending north-and-south and north-east-and-southwest. The latter have determined in large part the direction of the main streams. In the west especially, faults with a north-

west and south-east trend are locally important.

I am indebted to the University of London for a grant from the Dixon Fund to defray part of the field expenses. I wish to express my gratitude for expert assistance from Dr. G. L. Elles,

Quart. Journ. Geol. Soc. Vol. LXXXI, Pl. XXX

Fig. 1.—Volcanic breccia from the east side of Rhobell Fawr.



A. K. W. photo.

Fig. 2.—Pillow-lara, Craig-y-Benglog: showing the irregular form of the pillows, the gaping contraction-cracks, and the skins of hardened shale.



A. K. W. photo.



Quart. Journ. Geol. Soc. Vol. LXXXI, Pl. XXXI.

Fig. 1.—Basement Flags on the south-eastern flank of Moel Cors-y-garnedd.



A. K. W. photo.

Fig. 2.—Basement Flags east of the summit of Rhobell Fawr.



A. K. W. photo.

[The flags are seen dipping westwards at a low angle beneath a dolerite-sill.]





Prof. W. T. Gordon, Mr. H. C. Berdinner, Mr. A. J. Bull, and Mr. J. Pringle: to General J. Vaughan for permission to wander over his estate at will; for hospitality during several long vacations to Mrs. Mary Williams and family. Finally, the work has gained immensely from the chemical analyses supplied by Dr. H. F. Harwood, and from the criticism and advice received from Prof. A. Hubert Cox, Prof. W. G. Fearnsides, and Mr. S. W. Wooldridge, both in the field and in the laboratory.

EXPLANATION OF PLATES XXX-XXXII.

PLATE XXX.

Fig. 1. Volcanic breccia from the east side of Rhobell Fawr.

2. Pillow-lava, Craig-y-Benglog, showing the irregular form of the pillows, the gaping contraction-cracks, and the skins of hardened shale.

PLATE XXXI.

Fig. 1. Basement flags on the south-eastern flank of Moel Cors-y-Garnedd, showing the well-bedded character of the strata, and the type of current-bedding.

2. Basement flags east of the summit of Rhobell Fawr. The flags are seen dipping westwards at a low angle beneath a dolerite-sill.

PLATE XXXII.

Geological map of the Rhobell Fawr district, on the scale of 2 inches to the mile, or 1:31,680.

Discussion.

Prof. W. G. FEARNSIDES congratulated the Author on his very clear exposition of an interesting and difficult piece of mountain ground, which, although steep and rough, is not everywhere provided with the best of exposures. He thought that the Author's use of the term 'Basement Group' to include the many hundreds of feet of grit, flags, and ashes between the Rhobell volcanic group and the slate exposures which had vielded Glyptograptus tereti-

usculus, unfortunate.

He accepted the evidence of the great unconformity between the Cambrian (Lingula Flags and Tremadoc Slates) and the Rhobell andesites, but thought that there was in South Wales and the Lake District such good evidence of downward conformity below the Didymograptus-extensus Beds (through the zones of Tetragraptus and Dichograptus) that the Rhobell rocks must be included within the Arenig Series, and that they (and not the beds above the Garth Grit) must be accounted the local base of the Ordovician System.

He agreed that the series of sediments above the Garth Grit can be correlated bed by bed with that developed on Moel Llvfnant and Arenig, and mentioned that he had himself found the characteristic fossils of the Calymene Ashes, both in the gorge below

Allt Lwyd and on the Rhobell summit-outlier.

He hoped that the Author would look again before concluding that the upper (Llandeilo) volcanic group is newer than the zone of Nemagraptus gracilis; and that Llanvirn zones were never deposited in the Rhobell area. Slates with ill-preserved tuningfork graptolites make quite a show in a stream-course south of the River Wnion, close to the south-eastern corner of the Author's map, and concealment by faulting or under peat is perhaps a more reasonable explanation of their failure to crop out within the area

mapped.

The Author had described the later basic intrusions as gabbroid dolerite, although they have few characters in common with plutonic rocks. He had emphasized their frequency as sills at the horizon of the Garth Grit, and argued, therefore, that they must be older than the folding. The speaker suggested that they belonged to the same regional group as the andesitic dolerites of Arenig, and the great sills which at Tyddyn Dicwm (near Tremadoc) transgress along great thrust-planes all horizons, from the top of the *Lingula* Flags to the *Nemagraptus-gracilis* Zone of the Llandeilo, and have baked rocks which, though uncleaved, had previously been minutely folded.

By reason of its situation, the Rhobell area should afford critical evidence as to the relation of the movements which gave to the Lower Cambrian slates of the central district of the Harlech Dome their north-and-south cleavage, with those post-Silurian movements which imposed on the rocks of Cader Idris and the Arans their north-east and south-west cleavage, and he hoped that the map (when printed) would show all the available information concerning the dip and strike of the cleavage within the area mapped.

He welcomed the chemical analyses, and looked forward to the publication of the modern petrographical descriptions of the igneous rocks, which, with the stratigraphy and field evidence, would surely be an important contribution to the geological history of

volcanic activity in Wales.

Dr. H. H. Thomas expressed his appreciation of the beautiful piece of mapping that the Author had carried out in a difficult and complicated region. He (the speaker) was particularly interested in the Rhobell-Fawr Volcanic Series for, with Prof. A. H. Cox, he had recently mapped and described in Pembrokeshire a volcanic series which not only reproduced the lithological types of Rhobell Fawr, but undoubtedly occupied an identical geological horizon. In Pembrokeshire this series (Trefgarn Series) conformably underlay beds with a Dichograptid fauna, and thus, as the Author holds for the Rhobell-Fawr Series, they occupy a low position in the Arenig. He congratulated the Author on having placed in its proper position in the geological time-scale one more of the Lower Palæozoic volcanic series of Wales.

Prof. O. T. Jones wished to add his congratulations to the Author on having completed so skilfully a very arduous piece of

work in a difficult and inaccessible district.

The speaker was of the opinion that the unconformity at the base of the volcanic series was of greater significance than that between the 'Basement Beds' and the volcanic rocks.

It is unlikely that the 'Basement Beds' represent as low an horizon in the Arenig as is represented elsewhere in Britain; while outside Britain, particularly in the Baltic region and in parts of North America, there are strata which are probably somewhat older than any Arenig rocks in Britain. Among such are the Beekmantown Limestones of Vermont and elsewhere, which have decided Ordovician affinities. The unconformity between the Ordovician and the Cambrian which appears to occur in every section in Britain is, therefore, of greater significance than has been realized hitherto, and the Author's discovery that the Rhobell Fawr volcanic rocks occupy some portion of the interval between the two systems is, consequently, of great interest.

Dr. E. Greenly drew attention to the fact that, whereas the pebbly grits at the base of the *Extensus* Zone in North Wales are usually of moderate thickness, they expand to a very great thickness in the Tywyn-Trewan district of Anglesey, where shaly films which have yielded a *Tetragraptus* occur about 1200 feet below the shale with *Didymograptus extensus*: this must be the oldest graptolitic fauna yet known in North Wales. It is, therefore, not unlikely that these beds constitute a sedimentary equivalent of the

very early Ordovician volcanic series of Rhobell Fawr.

Prof. A. Hubbert Cox congratulated the Author on his successful completion of an arduous and difficult investigation. With regard to the similarity between the Rhobell and the Trefgarn Series, it is perhaps more than a coincidence that these two volcanic groups, each unique in its own district, should both occur at the southeastern margins of the greatest Cambrian masses of North and South Wales respectively. The Author's results were of more than local interest: they showed the importance of the interval between the Cambrian and the Ordovician, and helped to elucidate the history of that interval. They possibly furnish a clue to the date of the hornblendic intrusions, ranging from intermediate to ultrabasic, that are so widespread in Cambrian areas as far apart as South Wales, the Midlands, and the Highlands of Scotland.

The information as to the post Arenig sequence is almost all new. It furnishes further instances of the great stratigraphical variations that seem characteristic of North Wales, and especially of the Dolgelley district, where it is almost impossible to find two mountains on which the whole sequence remains constant. Thus, a traverse in the Arthog district would need 2 miles or more to cross the 3000 feet of strata that separate the Arenig Beds from the Nemagraptus-gracilis horizon; whereas the Author had shown that on Rhobell Fawr the corresponding interval is only a few hundred feet. It is one of the anomalies of North Wales that, within the are of volcanic rocks around the Harlech Dome, distinct groups of great thickness appear and disappear almost magically. It shows

how much work remains to be accomplished in linking up the

various areas recently resurveyed.

Prof. W. T. Gordon remarked that, although he could not usefully add to the discussion, he could not let the opportunity pass without congratulating his colleague (the Author) upon the successful culmination of a piece of research which had demanded long and patient attention. He had followed the Author's work during its course, and desired to pay tribute to the careful way in which every point had been considered, whether in the field or in the laboratory. The paper, and the discussion which had followed, indicated that the Rhobell-Fawr area was one of considerable interest, not only on account of the local rocks and of the conditions of their accumulation, but because it was a key-area in the elucidation of the general conditions under which the Ordovician strata of North Wales had been formed.

Mr. T. C. NICHOLAS congratulated the Author on the successful completion of a very important and arduous piece of work, and upon the interesting and lucid manner in which he had presented his results to the Society. His discovery of the age of the Rhobell Volcanic Group was a notable addition to our scanty knowledge of the events which took place during the interval between the Tremadoc Slates and the base of the Arenig, as developed in North Wales. In Anglesey and in Lleyn, the vast pre-Arenig denudation of the Cambrian beds, so strikingly displayed in the St. Tudwal's Peninsula, showed that this interval was an important one and far greater than would be suggested by the comparatively slight unconformity developed around the Harlech Dome. The speaker agreed with previous contributors to the discussion that the Rhobell Volcanic Group would only fill a small portion of this interval, and it was partly in the hope of finding deposits which might bridge the gap that he had some years previously transferred his attention to the Skiddaw Slates of the Lake District. His results were still far from complete; but, while it seemed certain that lower Ordovician horizons occur there than any that are found in North Wales, he was not yet convinced of the existence of any Cambrian beds.

Mr. G. M. Part, in congratulating the Author, also welcomed Prof. Gordon's reference to the more than local significance of this paper. He hoped, in reading the details, to find inspiration towards solving the Ordovician problems of North-Eastern Pembrokeshire, where the 'Inter-Arenig' suite described by Dr. Thomas & Prof. Cox was followed during later Ordovician times by acid volcanics, spilites, and gabbroid dolerites.

Mr. S. W. WOOLDRIDGE said that he had spent a considerable time with the Author on the ground, and had followed the progress of the investigation with the greatest interest. He referred to the difficulties and discomforts which attended such work in a wild and inaccessible country, a factor too often ignored in

assessing its value.

He was interested in the marked petrological differences between the Ordovician lavas of Dduallt and Craig-y-Benglog and their presumed time-equivalents at Arenig, only a few miles away to the north. Since no tectonic barrier separated the two areas, the facts acquired a peculiar significance in relation to problems of petrogenesis. It appeared that within the general 'co-magmatic region' of North Wales there were 'petrographic provinces' as

clearly marked as those originally described by Judd.

The sediments of the area are of great interest to students of younger rocks. The Lingula Flags of Moel Cynwch and Moel Hafod Owen were closely analogous to the familiar Claygate Beds in lithology, when due allowance was made for the great difference in age between the two series. Both series showed the phenomenon of rhythmic banding to advantage, and the same lithological type was found in parts of the Ordovician Basement Group. Such constant and regular sedimentary rhythms were strongly suggestive of a climatic cause, and it seemed to the speaker that the study of these beds should afford important data to the infant science of paleoclimatology.

He enquired whether the Author had obtained any evidence of the gaseous emanations presumably associated with the Rhobell

vent.

The AUTHOR expressed his appreciation of the cordial reception of his paper, and of the helpful suggestions made in the discussion. He thought that it would be unwise to substitute 'the Arenig' for the term 'Basement Group', as the latter includes only a portion of the former series. Prof. Fearnsides had misunderstood the Author's use of the term, which includes the three lowest members of the succession established in the Arenig Mountain district, but does not include the *Hirrundo* Beds, which are also of Arenig age.

In view of the differences of opinion as to the delimitation of the Cambrian System by British and Continental geologists, he thought it better to refer to the age of the Rhobell Volcanic Group as

'post-Tremadoc' rather than 'post-Cambrian'.

He contended that, compared with the great thickness of the Bifidus Beds in South Wales, and their considerable thickness in the Cader Idris country, their development in the Rhobell area could only be described as 'feeble'. Whether this is due to thinning-out or to strike-faulting remains in doubt. He pointed out that the occurrence of the Llanvirn Group at two points outside the area does not prove its occurrence within the area.

The terms 'gabbro', 'dolerite', 'basalt' were used with reference to the size of the grain of the rock, in the sense suggested by the

Committee on British Petrographic Nomenclature.

He agreed with Prof. Jones that the break beneath the Rhobell mass is the more important of the two, but the identical lithology of the three members of the Basement Group, whether resting upon the volcanic rocks or upon Cambrian slates, proved that a

considerable amount of pre-Garth-Grit levelling had taken place. He thought it possible that the highly decomposed state of the rocks of Rhobell, as also the prevalence of epidotization and pyritization, were the results of alteration dating from the closing

phases of the volcanic episode.

He regretted that there was not sufficient time to discuss adequately the petrological differences between the rocks of Arenig and those of Cader Idris. He had convinced himself that the differences are real, and probably resulted from differences in stress conditions and in the conditions of outpouring at the two independent centres of eruption. Submarine conditions, coupled with long-continued depression, had impressed a spilitic character upon the magma of the Cader Idris centre, while the normal andesites of Arenig Mountain might be correlated with relative elevation of the district and subaërial eruptions.

17. The Geology of the Cader Idris Range (Merioneth). By Prof. Arthur Hubert Cox, D.Sc., Ph.D., F.G.S. (Read February 25th, 1925.)

[PLATES XXXIII-XXXVII.]

CONTENTS. Page I. Introduction ... 539 (a) Physical Features of the Area. (b) History of Previous Research. II. The Stratigraphical Succession ... 543 (a) General Structure of the District. (b) Detailed Description of the Succession. III. The Intrusive Rocks 569 (a) The Dolerites. (b) The Granophyres. IV. The Tectonics 574 Transverse Folds. Longitudinal Folds and Faults. Shatter-Faults. V. Comparison with other Areas..... 584 VI. Summary and Conclusion 587 VII. Addendum: Traverses of the Cader Idris Sequence 590

I. Introduction.

(a) Physical Features of the Area.

The mountain-range of Cader Idris ¹ is formed by a great escarpment of Ordovician volcanic rocks which looks northwards across the Mawddach estuary towards the extensive area of Lower Cambrian rocks comprised in the Harlech Dome. The range has a general east-north-east to west-south-west trend, but the central portion runs almost due east and west. Along the range from east to west are the following summits, all exceeding 2000 feet in altitude:—Geu Graig, Mynydd Moel, Pen y Gader (2927 feet, the highest point), Cyfrwy (or The Saddle), Tyrau Mawr, and Craig y Llyn. Situate a little south of the main escarpment, but con-

¹ The chair or seat of Idris, a mythical Welsh giant.

nected with it by cols, are the heights of Mynydd Pencoed and Craig Cau. The range is bounded on the south by the Talyllyn Valley, and on the north by the valley running from Dolgelley past Llyn Gwernan. Both these valleys trend nearly north-east to south-west, and follow the lines of repeating faults; along them run the chief and almost the only roads within the district mapped.

North of the Llyn Gwernan Valley a smaller hill-range, or rather a series of ranges, intersected by the Gwynant Valley, intervenes between Cader Idris and the Mawddach estuary.

The greater part of the area included in the map (Pl. XXXVII) lies above the 1000-foot contour, much of it indeed above the 2000-foot line, so that most of the ground is uncultivated and given over entirely as pasturage for sheep. Cultivated ground is restricted to small patches along the Llyn Gwernan Valley and round the northeastern end of Tallyllyn lake. Most of these patches are situate either on gravelly boulder-clay or upon deltaic deposits. Many of the slopes are extremely precipitous, and exposures are everywhere abundant. Although every small hollow is infilled with peat and bog, there are no extensive areas of peat, with the possible exceptions of the hollow north of Craig y Llyn, and of parts of the upland valley between Mynydd y Gader and Cader Idris.

The area mapped is included in the Ordnance Survey 6-inch sheets Merioneth 37 (four quarter-sheets), 36 N.E. & S.E., 41 N.E. & S.E., and 42 N.E. & N.W., and in the Geological

Survey 1-inch map 59 N.E. (Old Series).

My attention was first drawn to this district, as a member of a field-class conducted by Prof. W. W. Watts; but it was not until 1912 that opportunity offered for attacking the geological problems presented.

(b) History of Previous Research.

The Cader Idris district has long been regarded as one of the areas in which 'Arenig' volcanic rocks are typically developed, and the fine mountain-cliffs with their alternations of sedimentary, volcanic, and intrusive rocks, have naturally attracted considerable attention. Early reference was made to the mountain by Aikin, while Sedgwick recognized the presence of the 'Festiniog': that is,

² Using the term as employed by Sedgwick (1847): that is, including the Arenig and the Lower Llanvirn of present-day nomenclature.

³ A. Aikin, 'Notes on the Geological Structure of Cader Idris' Trans. G. S. ser, 2, vol. ii (1829) p. 273,

On the 6-inch Ordnance Survey Map, the name 'Craig Cau' is given to the precipice north of Llyn Cau. Locally, however, the name 'Craig Cau' is always given to the summit south-west of Llyn Cau, and in this paper the term will be so applied. In all other cases throughout the paper, the nomenclature and spelling of the 6-inch Ordnance maps will be adopted.

Lingula-Flag and Tremadoc Groups below the 'contemporaneous porphyries' which form the main mountain-range. Our geological knowledge of the mountain is, however, mainly due to Ramsay, who gave a description of parts of the ground in his monumental work on the Geology of North Wales, while the results of the survey made by him and by other officers is shown on the 1-inch geological map. As a result of this work, many of the intrusive rocks were separated as 'greenstones' and 'felspathic traps', while the contemporaneous rocks were separated in part, and were supposed to be represented mainly by ashes, with few if any lavas.

All these volcanic rocks Ramsay considered to be of (what was later termed) Arenig age, and hence to be at a much lower stratigraphical horizon than the 'Bala' igneous rocks of Snowdonia. Neither the base nor the summit of the Merioneth volcanic rocks could, however, be determined at that time by palæontological evidence. Also, since the upward limit of the Tremadoc rocks had not been fixed in this area, the exact relations of the igneous rocks to the Tremadoc Series remained obscure. Ramsay himself speaks of the igneous rocks as being underlain, in part of the area, by representatives of the 'Lower Llandeilo' (that is, Arenig) beds. At the same time, he remarked on the possibility of some of the lowest igneous rocks, those on Mynydd y Gader, being of Tremadoc age, and this latter view seems to have found favour with later observers.

At a later date, the petrology of some of the rocks was described by Cole & Jennings, who apparently accepted Ramsay's view that volcanic rocks (as distinct from intrusive rocks) were mainly represented by tuffs and ashes. They considered that the products ejected became more highly silicated during the Arenig epoch, until finally there were flows of rhyolite similar in character to the Bala rhyolites of Snowdonia. With regard to the stratigraphy, these authors drew attention to the existence on Mynydd y Gader of a great thickness of volcanic rocks below certain pisolitic ironstones, then regarded as occurring near the base of the Arenig Series. This involved the classification of those lower igneous rocks as of Upper Tremadoc (or even Lower Tremadoc) age.⁴

Still later, Sir Archibald Geikie, in his general account of the volcanic rocks of Merioneth, gave the results of his observations on Cader Idris, and he was the first to indicate the probable existence of intermediate and basic lavas at various levels on the

¹ A. Sedgwick, 'On the Classification of the Fossiliferous Slates of North Wales, Cumberland, Westmoreland, & Lancashire' Q. J. G. S. vol. iii (1847) p. 133.

p. 133.
² Sir Andrew Ramsay, 'The Geology of North Wales' Mem. Geol. Surv. vol. iii (1st ed.) 1866, (2nd ed.) 1881.

³ 1-inch Geological Survey Map, Sheet 59 N.E. (Old Series).

⁴ G. A. J. Cole & A. V. Jennings, 'The Northern Slopes of Cader Idris' Q. J. G. S. vol. xlv (1889) p. 422.

mountain. He agreed with the view that the volcanic outbursts

began during Tremadoc time.1

More recently Mr. Lake & Prof. Reynolds have mapped and described the area extending from Dolgellev to Mynydd y Gader on the northern flank of Cader Idris.² They found that on Mynydd y Gader a great series of rhyolitic rocks intervenes between Tremadoc Beds vielding Dictyonema sociale below and Lianvirnian Beds with Didymograptus bifidus above. They accordingly assumed that the rhyolitic rocks belonged probably to the zone of Didymograptus extensus; but the relations of the volcanic rocks to the Tremadoc still remained uncertain. The mapping showed, however, that the lower boundary of the volcanic rocks transgressed the Tremadoc Beds and the various divisions of the Lingula Flags, so that it appeared probable that the lower limit of the volcanic series was a faulted junction. The beds immediately following the rhyolites were designated the Ashy Series'. These beds yielded D. bifidus and D. murchisoni, and were accordingly assigned in part to the Lower, and in part to the Upper Llanvirn.

The authors did not extend their work to the higher beds of the main Cader Idris range, on which the exact sequence and relations of the various rocks still remained obscure; while, owing to the complete lack of fossil records from these higher beds, it was only possible to correlate the rocks in a general way with those of other

areas in North Wales.

It accordingly appeared desirable that a detailed examination of the whole range should be made, in order to obtain some further knowledge of the sequence and distribution of the various

rock-groups. This investigation was then begun in 1912.

As the work progressed, it was found necessary to extend investigations to the region of foothills that intervene between Cader Idris and the Mawddach estuary. In this part of the work I was joined by Dr. A. K. Wells. An outline of the whole sequence was given in 19153; subsequently, a detailed account of the lower part of that sequence as seen in the foothills, was given in a joint paper (hereafter designated the 'Arthog paper').4 The present paper deals principally with the higher part of the sequence, as seen in the main range. The Ordovician-Silurian succession above the highest volcanic rocks of Craig v Llam has lately been described by Prof. W. J. Pugh.⁵

Ancient Volcanoes of Great Britain 'vol. i (1897) p. 176.

District' Rep. Brit. Assoc. (Manchester, 1915) 1916, p. 424.

⁴ A. H. Cox & A. K. Wells, 'The Lower Palæozoic Rocks of the Arthog-Dolgelley District' Q. J. G. S. vol. lxxvi (1920-21) p. 254. 5 Geology of the District around Corris & Aberllefenni 'Q. J. G. S.

vol. lxxix (1923) p. 508.

² 'The Lingula Flags & Igneous Rocks of the Neighbourhood of Dolgelley' Q. J. G. S. vol. lii (1896) p. 511; 'The Geology of Mynydd y Gader, Dolgelley' ibid. vol. lxviii (1912) p. 345.

3 A. H. Cox & A. K. Wells, 'The Ordovician Sequence in the Cader Idris

II. THE STRATIGRAPHICAL SUCCESSION.

The general stratigraphical succession is as follows:—

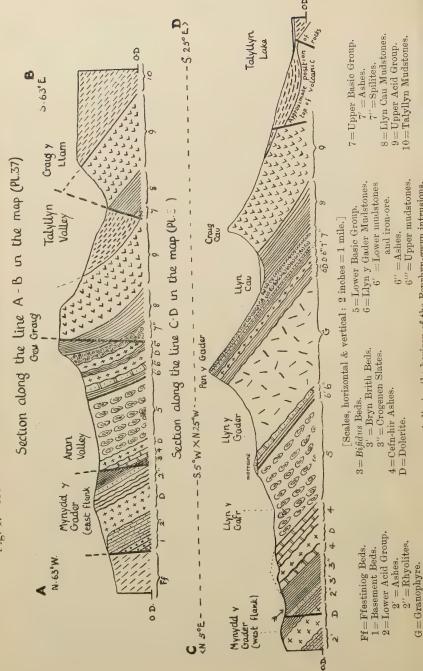
D		Thickness in feet.
BALA:	(10) Talyllyn Mudstones.	Grey-blue banded mud-
		stones, with Amplexo-
		graptus arctus in the
	(0) Haron Asid on Chat	lowest beds 4000
	(9) Upper Acid or Craig y Llam Group.	
	(8) Llyn Cau Mudstones.	itic ashes and lavas 900–1500
	(7) Upper Basic or Pen y	
	Gader Group.	with tuff and chert-
LLANDEILO: <	(6) Llyn y Godon Mad	bands 400–500
	(6) Llyn y Gader Mud stones and Ashes.	
	stones and Asnes,	with adinoles and massive ashes: Glypto-
		graptus teretiusculus . 450-60()
	Oolitic iron-ore	
	(5) Lower Basic or Llyn y	Pillowy spilitic lavas,
	Gafr Group.	with many ash- and
		shale-bands 1500
Lower	(4) Cefn-hir Ashes.	Massive agglomeratic
LLANVIRN:	(9) D:C3 D. 3.	ashes 500
LILANVIRN:	(3) Bifidus Beds.	
	Bryn Ruith Guite	with Didymograptus
	Crogenen Slates Bryn Brith Grits Moelyn Slates	\begin{cases} \text{with } Didymograptus \\ bifidus, \text{ etc.} \end{cases} \rightarrow 300-600
	(2) Lower Acid or Mynydd	
١	v Gader Group	l Rhyolitic lavas and akhes 500-1000
ARENIG:	y Gader Group. (1) Basement Beds.	Striped arenaceous flags
(and grits 150-200
	Unconformity.	200
UPPER (Tremadoc Slates.	
CAMBRIAN:	Lingula Flags.	
Cambalan, (Zingwa Plags,	

(a) General Structure of the District.

The distribution of the rocks is shown in the accompanying map (Pl. XXXVII). The various beds follow one another in regular succession, and dip, as a rule, steadily southwards or southwestwards at about 40°, until the Talyllyn Mudstones are reached, when folding and rolling of the beds immediately begin. The regular succession is modified to a certain extent by faulting: two shatter-faults—the Gwernan and Talyllyn Faults—cause a certain amount of repetition, and give rise to the Llyn Gwernan and Talyllyn Valleys, respectively north and south of the main range. There are also a few strike-faults that cut out groups of strata over considerable distances; these faults will be designated the Mynydd y Gader North, Mynydd y Gader South, Geu Graig, and Dysynni Faults respectively. Dip-faults are numerous, particularly along the course of the more massive rock-groups, but are of little structural importance.

Some complication of the general succession is, however, caused by the presence of numerous large intrusive masses, generally silllike in habit, but occasionally somewhat irregular. These intrusions, which include both acid and basic rocks, in some cases

Fig. 1.-Horizontal sections illustrating the geology of the Cader Idris range.



spread over and conceal the beds below, and in other instances arch up the strata, causing local faulting and local variations in

dip and strike.

The regular east-and-west strike is modified, especially in the western part of the area, by a minor series of north-and-south folds which cross the main east-and-west structures. These shallow north-and-south folds have a marked effect in causing sinuosities in the courses of the outcrops, complexities which are still further

increased by the high relief of the ground.

Despite, then, the general uniformity of dip, there are various factors -intrusive masses, shallow folds, and high relief-that frequently cause outcrops to depart from the normal strike, and to assume a markedly curving course. In consequence, the position of the main escarpment is not determined by the presence of any single hard bed, as in the case of escarpments of Mesozoic rocks in England. Jointing probably played a prominent part in determining the original position of the escarpment, which was subsequently modified profoundly by corrie-formation. Accordingly, we find the summit of the existing escarpment occupied in turn by pillow-lavas, granophyre, dolerite, slates, ashes, and rhyolites, each of these rock-types appearing more than once, so that the various outcrops advance to, and retreat from, the escarpment in an apparently capricious manner.

(b) Detailed Description of the Succession.

Upper Cambrian.

This paper is not concerned with the Upper Cambrian rocks, since the Cambrian strata in the western part of the district have already been dealt with (Arthog paper, p. 254), and those in the eastern part of the district have been described by Mr. P. Lake & Prof. S. H. Reynolds. It will be sufficient to recall that, throughout the western or Arthog area, there is a clear succession from Ffestiniog Beds, through the Dolgelley Beds, up to a high horizon in the Tremadoc Beds, and that this succession is similar, both lithologically and paleontologically, to the succession in the Arenig Mountain and Portmadoe districts north of the Harlech Dome.

In the Arthog area the Tremadoc Slates are followed, with a probable unconformity, by the basal grits and flags of the Arenig Series; the dips of the two series do not show any actual discordance, so far as can be ascertained. Farther east, that is, on the northern flanks of Mynydd y Gader, the relations of the Cambrian to the Ordovician rocks are disturbed by strike-faulting, which brings all the Upper Cambrian rocks in turn against Ordovician volcanic rocks. Consequently, the highest Tremadoc horizon actually proved to be present by Mr. Lake & Prof. Reynolds, was the Dictyonema Zone.2 The Mynydd-y-Gader

² Ibid. p. 514.

¹ Q. J. G. S. vol. lii (1896) p. 511.

North Fault that cuts out the remainder of the Tremadoc Group and all the Basement-Beds of the Ordovician, is sometimes visible in the bed of a small stream on the 800-foot contour, near the

northern boundary of the map (Pl. XXXVII).

The fault introduces into the sequence a gap that increases eastwards, until in the Aran Valley some 2000 feet of strata are missing. While the fault behaves as a true strike-fault with regard to the Arenig rocks, it is oblique to the strike of the underlying Cambrian deposits. It seems unlikely that the fault alone is responsible for the differences in the strike on the two sides. It is also unlikely that the fault has so great a throw as the 2000 feet that would be needed to restore the complete sequence in the Aran Valley. It is probable, therefore, that the fault masks an unconformity at the base of the Arenig, and that the unconformity accounts for the absence of the greater part of the missing strata, and for the differences in strike between the Cambrian and the Arenig rocks.

Ordovician: Arenig Series. (1) The Basement Group.

The Ordovician rocks begin with grits and sandy flags, that clearly form a local Basement Group to the Ordovician strata and compare closely with the Basal Grit and Extensus Flags of Arenig Mountain, and (except in less thickness) also with the Basal Arenig Beds of St. Tudwal's Peninsula. The change from the argillaceous Tremadoc Beds to the arenaceous Basement Beds takes place quite suddenly: nevertheless, as stated above, no discordance of dip can be observed. The Basement Beds are well seen in the Arthog Valley, where their development has been described in detail (Arthog paper, p. 265), so that no further account is needed here.

East of the Gwynant Valley the Basement Group is cut out over a considerable distance by strike-faulting. Similarly, along the whole northern front of Mynydd y Gader the group is not seen owing to strike-faulting, so that its existence naturally remained unsuspected by Mr. Lake & Prof. Reynolds. The presence of numerous dark quartz-grains in the lowest ashes suggests, however, that the arenaceous beds must be at no great distance

below the surface.

East of Mynydd y Gader beds referable to the Basement Group appear around Tyn-y-bryn,³ on the east side of the Aran Valley, a mile and a quarter above Dolgelley. The beds at this locality are somewhat different from the typical Basement Beds as seen farther west in the Arthog area; they are rather dark, ashy, felspathic grits, and they often weather somewhat like a dolerite, but may be identified by the presence of numerous small pebbles or lapilli, with occasional pebbles measuring up to 6 inches in diameter.

¹ W. G. Fearnsides, Q. J. G. S. vol. lxi (1905) p. 618.

² T. C. Nicholas, *ibid.* vol. lxxi (1915) p. 108.

³ Immediately beyond the northern boundary of the map (Pl. XXXVII).

This felspathic ashy type characterizes the uppermost portion of the Basement Group. It does not attain great prominence in the Arthog area, but becomes increasingly important eastwards, and attains its greatest development east and north-east of Dolgelley, where it has been found by Dr. A. K. Wells to cover large areas in the country near Rhobell Fawr.

At Tyn-y-bryn the flags and quartzites that should constitute the major portion of the Basement Group are not present, and the ashy grits are only separated from the Ffestiniog Beds by a dolerite sill. It is evident that this sill covers an extension of the

Mynydd-y-Gader North Fault.

(2) The Lower Acid (or Mynydd-y-Gader) Rhyolitic Group.

This first of the four volcanic groups of Cader Idris follows directly upon the arenaceous beds of the Basement Group. It is the most thoroughly acid of the four volcanic groups, and consists entirely of rhyolitic lavas and tuffs. The lavas are best developed in the middle portion of the group, the principal tuffs occurring both above and below the lavas. As is only to be expected, however, bands of tuff may appear at any horizon in the group.

The group attains its greatest thickness in the eastern part of the district, especially on the southern slopes of Mynydd y Gader, where the rocks were studied by Mr. Lake & Prof. Reynolds. These authors showed that, on the south-eastern side of Mynydd y Gader, there is a fine development of nodular, banded, and compact rhyolites, which were described in detail; followed westwards, first the nodular and then the banded rhyolites die out, so that on the western flanks of the hill it becomes a difficult matter to separate the lavas from their tuffs with any degree of accuracy.

The westward thinning of this rhyolitic group was confirmed by the examination of the ground west of Gelli-lwyd, whence the volcanic rocks form an almost unbroken band right away to the Arthog Valley. Throughout this western outcrop the rocks are mainly fine-grained rhyolitic tuffs, though actual flows may be developed to a certain extent (Arthog paper, p. 268). A peculiarity of this rhyolitic group is that it is always intimately associated with sill-like masses of dolerite. For further details the reader is referred to the papers mentioned above.

The age of the beds was proved, within certain limits, by the occurrence among the volcanic rocks of slate-bands (the Pont-Kings Slates) which contained a mixture of extensiform and tuning-fork graptolites. These slates are restricted to the western or Arthog district, and they thin out eastwards simultaneously with the eastward thickening of the volcanic products. Thus the slates could not be distinguished on Gelli-lwyd or towards

Dolgelley.

Lower Llanvirn: (3) The Didymograptus-bifidus Beds.

General remarks.—Along the lower slopes of Cader Idris the Bifidus Beds are cut out by the Mynydd-y Gader South Fault over the greater part of the area in which they might be expected to occur. Consequently, the only important occurrences are those on the western and on the eastern flanks of Mynydd y Gader. Even where the series does occur, the detailed stratigraphical relations are so obscured by the presence of intrusive rocks, by major and minor faulting, also by a probable overlap, that the true details of the sequence could only be made out by reference to the Arthog district, where the sequence is both more complete and more straightforward.

In that ground the main mass of the *Didymograptus-bifidus* Beds has been shown (Arthog paper, p. 274) to be capable of a

threefold division into:-

(iii) Crogenen Slates above.

(ii) Bryn Brith Beds (ashy grits).

(i) Moelyn Slates, with associated ashes below.

It was found, however, that the full succession was only present in the ground west of the Gwynant River; whereas farther east the Moelyn Slates were missing, owing to a local overlap at the base of the Bryn Brith Beds, which caused these latter to rest in certain localities directly on the rhyolitic rocks of the Lower Acid Group.

Thus the slate-band is absent on Gelli-lwyd, where the Bryn Brith Beds are often so similar to the rhyolitic ashes upon which they rest, that it is difficult to establish the boundary-line between

the two groups.

Further, since the overlap developed pari passu with the eastward thickening of the underlying volcanic rocks, it appeared to be a case of overlap against the slopes of a submarine volcanic pile. Similar relations hold in the area on the western flanks of Mynydd y Gader, where the rocks of Gelli-lwyd are repeated by the Gwernan Fault.

Whether this eastward overlap continues, or what happens among the *Bifidus* Beds farther east, it is impossible to say, because all along the southern flanks of Mynydd y Gader a considerable thickness of strata, including the whole of the *Bifidus* Beds, is cut out by the Mynydd-y-Gader South Fault, which brings together the Lower Acid and the Lower Basic Volcanic Groups. Even where a portion of the *Bifidus* Series eventually reappears in the Aran Valley, the sequence is possibly reduced by strike-faulting: consequently, no deductions can be drawn as to the progress of the overlap.

(3') The Bryn Brith Beds near Llyn Gwernan.—On the western side of Mynydd y Gader, where the rocks of Gellilwyd are repeated by the Gwernan Fault, the Bryn Brith Beds form a much faulted band, that swings round the flanks of the hill. This band strikes approximately north-west and south-east, that is, in a direction quite different from the usual strike in the Cader Idris district. The departure from the normal is caused by a local twist of the strata, due to the combined effects of the Gwernan Fault and the great doleritic intrusion of Mynydd y Gader. The outcrop is only traceable for a distance of half-a-mile, as the beds are eventually cut out by a branch of the Mynydd-y-Gader South Fault, the effect of which is further helped by a small transverse fault.

The Bryn Brith Beds are here, as elsewhere, very variable deposits, including coarse conglomerates or agglomerates, grits, silicified mudstones, and ashy shales. Exposures generally are not satisfactory in this ground. The lowest beds are seen on the Cader Idris path, about 800 yards south-south-east of Gwernan Villa, where the path runs for a few yards alongside a small stream which descends from Mynydd y Gader. These lowest beds are coarse conglomerates, the fragments including pebbles of rhyolitic material and numerous pebbles of a vesicular andesite that has not been found in situ in the underlying beds. These fragments may attain a diameter of 6 inches, but the size rapidly diminishes in the upper part of the bed.

Coarse agglomeratic rocks, mainly composed of large blocks of silicified slate similar to those of Gelli-lwyd, are seen in association with grits on various small hillocks south of the Old Towyn Road and south-west of Gwernan Villa. The group is, however, much better exposed on the higher parts of the opposing slopes of

Gelli-lwyd.

Elsewhere, as, for example, above the farm of Tyddyn-mawr, the rocks consist mainly of rather fine-grained ashy grits associated with a considerable amount of slate, giving the impression that one is dealing with an entirely different set of beds. Rapid lateral variations in the character of the sediment appear, however, to be characteristic of the Bryn Brith Beds in other parts of their outcrop. The ashy grits near Tyddyn-mawr weather grey, and break away in rather massive rectangular blocks, so that they have formerly been mistaken for, and mapped as, dolerite. The grits pass upwards by a complete transition into the Crogenen Slates.

(3") The Crogenen Slates.—These slates have a longer outcrop than the Bryn Brith Beds, since they extend for a distance of about a mile before they are finally cut out by the Mynydd-y-Gader South Fault. The beds are much disturbed by offshoots of the strike-fault, and by a great number of small transverse faults that help the strata to elbow round Mynydd y Gader. Since, too, the small features made by various hard strata have been considerably modified by the numerous streams descending from Mynydd y Gader, the relations of the various beds were not easy to determine.

The lower beds of the group are seen above Tyddyn-mawr

where they follow conformably upon the ashy grits of the Bryn Brith They consist of dark slates, with one or two intercalated beds of massive fine-grained rhyolite-tuff. The lowest of these tuff-intercalations is exposed on the hillside above Tyddyn-mawr

Farm; a higher bed is visible in the farmyard.

A full sequence of the Crogenen-Slate group appears above the intrusive rocks of Penrhyn-gwyn, from which the strata strike eastwards until they are cut by the Mynydd-y-Gader South Fault. Two ash-beds in the lower part of the group give rise to conspicuous features above the Penrhyn-gwyn intrusions and cause waterfalls in the neighbouring ravines. The lower of these two bands consists of ashy grits and hard ashy slates, and represents practically the top of the Bryn Brith Group. The higher bed is made of a massive fine-grained rhyolitic tuff similar to the rock exposed in the farmyard of Tyddyn-mawr, and quite possibly representing one and the same bed. A similar band of fine-grained rhyolitic ash occurs low down in the Crogenen Slates at Llynau Crogenen.

The main mass of the slate-group is exposed in Penrhyn-gwyn Quarry. The slates are dark blue and well cleaved. When broken across the cleavage they are seen to be almost black, and the slates are darker than any other Ordovician slates in the district, except those that contain the oolitic iron-ore. The slates are usually rather micaceous, and they generally contain a certain amount of ashy material, which is frequently abundant enough to form definite little ashy bands several inches thick. This is quite apart from the main ash-bands mentioned in the preceding paragraph. The beds in the quarry dip 20° southwards, while the cleavage is inclined south-westwards at a slightly greater angle.1 Around Penrhyn-gwyn the Bifidus Slates are more completely cleaved than any Bifidus Beds that I have seen in other parts of Wales. Nevertheless, quarrying of the slates has been completely abandoned, probably because the quality was not so good as that of the Bala slates of the Corris Valley.

In consequence of the high degree of cleavage, fossils are more difficult to obtain than is usually the case in Bifidus Beds. Mr. Lake & Prof. Reynolds were the first to record fossils from these beds. They found Didymograptus murchisoni (Beck) and Orthograptus calcaratus var. priscus Elles & Wood, and accordingly they regarded the beds as belonging to the zone of D. murchisoni. I was, however, fortunate enough to obtain D. bifidus and D. murchisoni var. geminus, so that it would appear that these beds really belong to the zone of D. bifidus. The occasional presence of forms comparable with D. murchisoni is by no means exceptional in the Bifidus Beds of South Wales and

elsewhere.

From a stratigraphical and structural point of view also, there

² Q. J. G. S. vol. lxviii (1912) p. 348.

¹ See description by Sir Archibald Geikie, 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 180.

can be no doubt that the slates of Penrhyn-gwyn are the equivalents of the well-marked band of slates traceable from Llynau Crogenen to Gelli-lwyd. The Lower Llanvirn age of the latter slates has been clearly proved, since they yielded at numerous localities the characteristic fossils of the Bifidus Zone: namely, Didymograptus bifidus. D. stabilis, and D. nanus (Arthog paper, p. 278). Thus the Lower Llanvirn age of the Penrhyn-gwyn slates is also placed beyond doubt.

The Crogenen Slates tend to form smooth and often boggy ground, with exposures only along the stream-courses. Across the smoother ground the various ash-bands make distinct features. The gradual wedging-out of the smooth grass-covered outcrops, as the slates approach Mynydd y Gader from the west and become pinched out by the faults, is a noticeable feature, well seen from

many view-points along the Cader Idris path.

Over that part of the outcrop which is nearest to the Llyn-Gwernan Valley the characteristic smoothness of the ground is wanting, owing to erosion by the numerous rejuvenated streams, while the presence of ash-bands and of numerous transverse faults also complicates the physical features.

The Bifidus Slates of the Aran Valley.—It has been shown above that the Bifidus Beds are well developed only on the south-western flank of Mynydd y Gader, and that along the southern side of the hill the beds are entirely cut out by the Mynydd-y-Gader South Fault. A mile or two farther east the Bifidus Beds reappear to form a small strip along the south-eastern flanks of the hill and across the Aran Valley. The beds consist of blue slate, rather ashy and flaggy, which yielded D. bifidus to Mr. Lake & Prof. Reynolds, at a point near a trial-level on the northern bank of the Aran. The exact position which these beds occupy in the Bifidus Series is not clear, as relationships are obscured by faulting, and the characteristic Bryn Brith beds are missing, owing either to attenuation, to faulting, or to overlap.

On the north side the beds appear to follow conformably upon the ashes of the Lower Acid Group, while on the south side they are succeeded by the Cefn-hir Ashes. Followed north-eastwards, this apparent sequence remains constant for about a mile and a

half along the strike.

But it is difficult to say to how great an extent this apparent sequence represents the full succession, for the Mynydd-y-Gader South Fault extends into this outcrop, and must cut out some of the beds, although it is not easy to determine the exact position of the fault in the slaty strata. The diminished thickness of the overlying Cefn-hir Ashes suggests that the fault passes between the Ashes and the Bifidus Beds. If so, the Bifidus Beds of the Aran Valley must include the lower horizons of the Bifidus Series. The lithology of the beds and their rather unfossiliferous nature would agree with this view.

We have, then, to account for the fact that there is little or nothing in the Bifidus Beds of the Aran Valley to correspond with the gritty Bryn Brith Beds of Gelli-lwyd and the Arthog area. It is uncertain whether their absence is to be ascribed to lateral attenuation, to faulting, or to overlap. A few feet of grit-beds of Bryn Brith type do occur about 50 feet above the base of the slates, but such beds are not uncommon elsewhere in the lower part of the Bifidus Series in this district. Therefore, it is not safe to conclude that these gritty beds represent an attenuation of the Bryn Brith Beds, although they may possibly do so. Moreover, the strata are certainly traversed by small branches of the Mynyddy-Gader Fault, but I have not been able to satisfy myself that these faults have any considerable throw.

As to the possibility of an overlap, it was shown in the Arthog paper (p. 276) that the Bryn Brith Beds overlap the lower part of the Bifidus Shales as they are followed eastwards; and it is possible that the overlap continues to increase in importance eastwards, until the Bryn Brith Beds themselves become overlapped by higher

Bifidus Shales.

This interesting point cannot, however, be confirmed within the area mapped, owing to uncertainty as to the amount of faulting. But it is beyond doubt that there is a considerable eastward attenuation of the Bifidus Series, whether by overlap or by actual attenuation of the strata, and this eastward attenuation seems to continue for some distance, since the Bifidus Beds in the Arenig district 1 are much thinner than on Cader Idris.

The Penrhyn-gwyn lava.—A porphyritic 'andesitic' lava occurs at the top of the Crogenen Slates, but is not often exposed, partly owing to strike-faulting and partly to its position at the base of a scarp formed by the massive Cefn-hir Ashes above. lava is visible at points where the 1000-foot contour crosses the two branches of the stream above Penrhyn-gwyn, also in the upper part of Penrhyn-gwyn Quarry. Farther east, some torn lenticles are visible along the Mynydd-y-Gader South Fault, especially where that fault crosses the small stream that flows due westwards from Mynydd y Gader towards Penrhyn-gwyn. Still farther east a similar rock can be picked up at intervals across the Aran Valley, always at the same stratigraphical horizon.

Its unique character and its position along a constant horizon over more than 6 miles furnish strong evidence that the rock is contemporaneous, even though it appears to cause a certain amount of contact-alteration to overlying beds at some localities. Such alteration by submarine flows is, however, not uncommon. At one point on the south-western flank of Mynydd y Gader a separate small mass of similar rock occurs some 150 feet lower in the

Bifidus Series. This smaller mass is probably intrusive.

The main band is about 20 feet thick, is highly vesicular, and

W. G. Fearnsides, 'The Geology of Arenig Fawr, &c.' Q. J. G. S. vol. lxi (1905) p. 623.

has locally a slight tendency to pillow-structure. Its upper portion shows a rude cleavage, which becomes more pronounced with the incoming of thick slate-masses on its upper surface. This lava is readily distinguished from all other lavas on Cader Idris by its pronounced porphyritic character; it is crowded with porphyritic felspars which range up to a quarter of an inch in length.

It may be recalled that some miles farther west towards Llynau Crogenen a thin pillow-lava is intercalated in the Cefn-hir Ashes (Arthog paper, pl. xx). This western flow is not however identical with the Penrhyn-gwyn flow, for the western lava occurs some 100 feet above the base of the ashes, is distinctly more basic, and has a better developed pillow-structure than the Penrhyn-gwyn

lava.

(4) The Cefn-hir Ashes.

The Crogenen Slates are succeeded abruptly by a group of ashes—the Cefn-hir Ashes—which take their name from the jagged ridge of Pared y Cefn-hir above Llynau Crogenen. This group is about 500 feet thick, but along the northern front of Cader Idris the outerop is greatly expanded by doleritic intrusions. Most of the beds composing the group are very massive. Some of them consist essentially of extremely fine-grained andesitic dust; such beds are often well-laminated, and have a platy or sometimes a splintery jointing. Other beds are more agglomeratic, with lapilli of acid material, either a rhyolitic, or a silicified andesitic, lava or ash. Yet other beds are composed mainly of small broken felspars, and show a well-marked streaky lamination on weathering.

The massive beds are succeeded, as in the Arthog district, by about 150 feet of slates and slaty ashes with a few intercalations of harder ash-bands. Among this slaty group is a slate-band marked by the constant presence of chips and pebbles of rhyolitic material; this band has proved useful in mapping, on account of

its distinctive character.

The ashy slates yielded *Didymograptus bifidus* at an exposure in the northern branch of the stream, in the upland hollow between Cader Idris and Mynydd y Gader. Fossils, however, are scarce and the forms are quite small, although so high up in the Llanvirn Series; the small size of the graptolites is possibly due to the ashy nature of the sediments.

The Cefn-hir Ashes are concealed by the Penrhyn-gwyn granophyre in the immediate neighbourhood of the Gwernan Fault-Valley. They emerge from beneath the granophyre in the neighbourhood of the pony-track, and for a short distance they are seen to rest upon the Crogenen Slates of the Penrhyn-gwyn outcrop. Nearer Mynydd y Gader, the Cefn-hir Ashes are faulted against the rhyolitic rocks of the Lower Acid Group, the whole of the Bifidus Beds being cut out. Hereabouts the ashes are well exposed. Farther east the fault cuts them out entirely over a space of a

mile along the southern flank of Mynydd y Gader, but a small part of the group appears once more in the Aran Valley. Thus, east of Llynau Crogenen the full thickness of the group is nowhere displayed over a horizontal distance of 7 miles, owing to the complexities introduced by faulting and by intrusions. This serves as a good illustration of the extent of ground that needs to be examined in this district before one can be sure that the full

sequence has been ascertained.

As might be expected in strata that include much coarse-grained material, the group varies somewhat in a lateral direction. It is probably for this reason that a slate-band, present in the lower part of the ash-group on Pared y Cefn-hir near Llynau Crogenen, has not been seen anywhere in the neighbourhood of Mynydd y Gader. It is, of course, possible that the lowest ashbeds with an accompanying slate-band are everywhere faulted out; but, in view of the extent of ground examined, it is more likely that the slate-band dies away eastwards. The slates at the top of the ash-group are more constant, as they can be identified at intervals all the way from Llynau Crogenen to the Aran Valley.

(5) The Lower Basic or Llyn-y-Gafr Spilitic Group.

The Lower Basic Group forms the second of the four volcanic groups on Cader Idris. It consists of a thick series of pillowy lavas, accompanied by related intrusions, and with intercalated ash- and slate-bands. Ashy and slaty material is especially abundant in the lower half of the group. The group at its maximum development is about 1500 feet thick.

The volcanic rocks make a prominent feature on the northern slopes of Cader Idris, between Llyn y Gafr and Llyn y Gader. East of Llyn y Gafr the feature ends abruptly, having been destroyed by corrie-formation; but the outcrop continues unbroken, although concealed by superficial deposits, and the volcanic rocks (together with intrusive dolerites) occupy the whole of the upland

valley between Mynydd y Gader and Mynydd Moel.

The Lower Basic Group attains its maximum development in the ground immediately north of the main peaks of the Cader range: that is, from Mynydd Moel to Tyrau-mawr. Eastwards or westwards respectively from these points the thickness decreases rapidly, principally owing to decrease in the number of flows. Good sections through the upper part of the series are to be found 200 to 300 yards west of the path between Llyn y Gafr and Llyn y Gader.

The lavas are all thoroughly basic, and consist of spilites and variants of the spilite type. Where the group is at its maximum the number of individual flows is considerable, although difficult to estimate exactly. Typically, each flow is markedly columnar throughout its lower and middle portions, whereas the tops of the flows show beautiful pillow-structure. The pillows are often of very large size, and they are sometimes noteworthy for the

exceptionally large amount of slate that surrounds them. In one case as much as 3 feet of slate was observed between the pillows.

The columnar portions of the lavas are often of coarse texture, and look (especially where the rocks have been epidotized) exactly like some of the associated dolerites, while the pillowy upper portions are frequently unexposed over large stretches of ground. These pillowy rocks are often considerably affected by cleavage. Thus the true character of these rocks long remained obscure. The whole series is denoted as intrusive diabase on the 1-inch Geological Survey map, although its composite nature was recognized by Ramsay. The probable presence of scoriaceous lavas among these rocks was first suggested by Geikie. 2

Some of the ashy and slaty bands that occur intercalated with the lavas show fairly distinctive characters, and appear to be constant features, since they may be picked up at intervals over a wide area; others are less distinctive, and cannot be followed far along the strike. Pyroclastic and sedimentary material is more abundant in the lower half of the volcanic group than in the upper. The more important outcrops are indicated on the map

(Pl. XXXVII).

The ashes are of various types. A common type in the lower part of the group is a massive or streaky rock, consisting largely of broken felspars set in a dark fine-grained matrix, which is sometimes scanty, sometimes abundant. Other types are of finer All tend to show a well-marked lamination while still retaining a massive character. At higher levels come dark banded rocks in which broken felspars are set in an argillaceous matrix; also well-banded fine-grained featureless 'schalsteins' (that is, more basic ashes), which may contain occasional lapilli, \frac{1}{2}-inch seams of chert, and 6-inch seams of hard slate. The slate-seams are well cleaved, even when set in massive uncleaved ashes. All these ashes are very massive and well-jointed. Near the summit of the volcanic group is an agglomeratic band distinctive enough to have proved useful in mapping. It consists entirely of sheared fragments of vesicular pillow-lava, and presents a characteristic rubbly appearance; its outcrop is indicated on the map (Pl. XXXVII).

Age of the Lower Basic Group.—Two types of slate may be distinguished among the volcanic rocks. The slates in the lower half of the group are grey-blue, and bear a general resemblance to the *Bifidus* (Crogenen) Slates below; they only differ in being somewhat harder, less pyritous, and not so well cleaved as the typical *Bifidus* Slate. This is the case, whether the slates occur in definite bands 2° feet or more thick, or merely as large masses involved among the lava-pillows.

The slates in the higher part of the Lower Basic Group are much darker, being blue-black to almost black, and are softer and

^{1 &#}x27;Geology of North Wales' Mem. Geol. Surv. vol. iii, 2nd ed. (1881) p. 31. 2 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 183.

highly pyritous. One such band yielded numerous fragmentary graptolites which, unfortunately, were too imperfect to be identified.

They appear, however, to belong to Llandeilo types.

The lower limit of the Lower Basic Group is definitely fixed as being quite high up in the *Bifidus* Series, and the group seems to extend well up into the Llandeilo. Fossiliferous beds of the *Murchisoni* Zone are nowhere represented. The upper limit of the volcanic group is unfortunately not so clearly established palæontologically, and whether the volcanic rocks extend up through nearly the whole of the Llandeilo Series is uncertain.

The Oolitic Iron-Ore.

The Lower Basic Group is overlain by some 10 to 20 feet of dark mudstones in which onlitic iron-ore is more or less abundantly developed. The beds form a well-defined band that can be traced almost everywhere at (or near) the base of the main scarp of the Cader range; consequently, it serves as a most useful horizon in mapping the country. The exact proportion of mudstone to iron-ore varies along the strike, and trials have been made at several places, notably at Ffordd Ddu (due south of Arthog), while at Cross Foxes, 6 miles east of Ffordd Ddu, there are fairly extensive workings.¹

The iron-ore has been described by Ramsay, Geikie, and Cole & Jennings (for references, see p. 541). The last-named authors gave a petrological account, and concluded that the ore-band probably originated from the alteration of an oolitic limestone. The bed is similar to certain other occurrences of oolitic iron-ore in the Ordovician of Wales, as, for example, those at Abersoch

(Lleyn peninsula) and Anglesey.

The oblitic ore of Tremadoc was considered by Prof. W. G. Fearnsides to have originated as a metasomatic deposit, due to the metamorphic action of intrusions and localized by fault-planes.² The ore at Abersoch is, however, regarded by Mr. T. C. Nicholas

as a definite sedimentary stratum.³

In the Cader Idris area it is certainly noticeable that the best development of iron-ore, that at Cross Foxes, appears where overlying intrusions approach most nearly the ferruginous horizon. Nevertheless, the ore is considered to represent a definite sedimentary deposit. Certain specimens collected at Ffordd Ddu are especially instructive in this respect. They show rounded (and sometimes elongated) pebbles of oolitic ore, scattered more or less abundantly in a mudstone which is otherwise practically normal in character. The structure shows best on well-weathered surfaces, and is not clearly seen along fresh fractures.*

^{1 &#}x27;Special Reports, vol. xiii: Iron-Ores' Mem. Geol. Surv. 1920, p. 27.

Rep. Brit. Assoc. (Leicester, 1907) 1908, p. 510; Geol. Mag. 1907, p. 422;
 Q. J. G. S. vol. lxvi (1910) p. 172.

³ Q. J. G. S. vol. lxxi (1915) p. 125.

⁴ Since the true structure is only revealed by weathering, the best specimens are to be found, not in the quarry at Ffordd Ddu, but in some of the neighbouring walls, which are made up of material taken from the quarry.

A superficial examination suffices to show that the rounded shape of these particular pebbles is not because they represent 'augen' of hard material, sheared into rounded or lenticular shape through the action of cleavage-stresses. On the contrary, the bodies are evidently true pebbles closely analogous to the clay-balls that are of such frequent occurrence in the sandstones of the Old Red and the Trias. They represent a partly consolidated sedimentary deposit that has been broken up by penecontemporaneous current-action, and rolled into balls which have become embedded in a

deposit of slightly later age.

This type of deposit occurs at other localities, but it is not often seen, on account of the weathering conditions being unfavourable. Also, at most localities, the original structure is more or less obscured by cleavage, which, acting on an admixture of hard and soft material, has naturally caused some shearing along the junctions. Further variation arises from the fact that the original colitic deposit was not always so completely broken up by contemporaneous current-action. At most localities, therefore, the strata appear as an admixture of augen of iron-ore of varying size and in varying quantity, embedded in shattered slaty material. This is the appearance, as seen in trials below Tyrau-mawr, below Llyn y Gader, below Mynydd Moel, and in other trials towards Cross Foxes. At all these localities the excellent description given by Mr. T. C. Nicholas 1 of the pisolitic iron-ores near Abersoch might be applied almost word for word, so much so, that further description of the Cader Idris rocks seems unnecessary.

As the beds are followed eastwards towards Cross Foxes, an important change appears to occur rather suddenly, at a point a little over half a mile south-west of Cross Foxes. The ore here becomes much purer, with less admixture of argillaceous material. At the same time, the bedding is more obvious, the strata occurring in beds each some 5 feet or more thick. Cleavage has practically failed to get any grip on these hard thick beds. The quarries and levels opened in these strata have been described by Dr. R. L. Sherlock.² This is the locality at which large overlying doleritic intrusions approach most nearly the ore-bed. But even here the dolerite is separated from the ore by some 100 feet of slate with associated massive ash-bands, and these intervening strata, except for the few feet immediately adjacent to the dolerite, do not display any evidence of contact-alteration or mineralization. Therefore, the evidence is all against any direct connexion between the presence of doleritic intrusions and the occurrence of the ironore. The same is true farther west, where similar relations are repeated between the iron-ores, the overlying slates, and the intrusive rocks, although in the west the intrusive rocks are granophyres (not dolerites).

^{&#}x27;Geology of the St. Tudwal's Peninsula (Carnarvonshire)' Q. J. G. S. vol. lxxi (1915) p. 123.
'Special Reports. vol xiii: Iron-Ores' Mem. Geol. Surv. 1920, p. 27.

The oolitic grains in all the Cader Idris iron-ores are rather small. Nowhere have large grains been observed, comparable with the large pisolites of the ore at Llandegai, near Bangor

(Carnarvonshire).

Stratigraphically, the ore is separated from the Lower Basic Group below by a few inches of dark badly-crushed shale, which in no way differs from the shale found intermixed with the ore itself. Although this underlying slate is so badly crushed, I could not detect any evidence of extensive thrusting or other faulting at this horizon. I regard the crushing as the natural result of pinching a thin film of soft argillaceous material between two more massive formations—the volcanic rocks below and the ironstone above.

Evidence for a possible non-sequence at the base of the ironstone was also sought in vain. It is well known that breaks sometimes occur beneath oolitic ironstones, as, for example, at the base of the Northamptonshire Ironstone and at the base of the Yorkshire Dogger, while there are pronounced breaks (ascribed, however, to faulting) below the Ordovician magnetite-ironstones of the Tremadoc and Abersoch districts. But in the Cader Idris district no direct evidence could be obtained for a break of any kind, either large or small. It is true that the oolitic ore and its associated shales succeed the volcanic rocks very suddenly, without any suggestion of a transitional zone. It is also true that there are slight differences in the exact type of volcanic rock, usually an ash, on which the ironstone rests. But such differences are no more than might be expected when a volcanic series is followed for some miles along the strike. While, therefore, the possibility of a break is not ruled out, there is no direct evidence in support of its presence.

Age of the ore.—Only very fragmentary fossils have been obtained from the ironstone and associated beds. Fragments of brachiopods may sometimes be seen, while pyritized graptolitesiculæ are often fairly abundant. The siculæ are probably referable to *Climacograptus schärenbergi* Lapworth. Shales immediately overlying the ironstone have yielded *Glyptograptus*

teretiusculus Hisinger.

As stated above, slates near the top of the Lower Basic Grouphave yielded graptolites of Llandeilo types. The iron-ore itself therefore appears to be of Llandeilo age, but the fossils in the orebed and in the under- and overlying beds are not sufficient to fix the horizon more exactly. It is therefore uncertain whether the Cader Idris ironstone is at approximately the same level as the similar ores of Tremadoc and Anglesey, which have been referred to the zone of Nemagraptus gracilis, or to the uppermost portion of the zone of Glyptograptus teretiusculus.

Origin of the bed. — From whatever standpoint it is approached: petrological, structural, or stratigraphical, there is no

evidence that the origin of the ore is connected with the presence of intrusive rocks, or that it occurs in a crush-belt. In fact, the evidence is all the other way, and to the effect that the ore-bed occupies a definite stratigraphical level, and resulted from normal processes of sedimentation. The occurrence may be explained as probably due to the same processes as those that gave rise to the rather similar beds in Newfoundland, where the ores and their probable mode of origin have been so ably studied by Mr. A. O. Haves.¹

The Newfoundland deposits are of Lower Ordovician age, and are interbedded with graptolitic shales, etc. They are oolitic ores in which the oolites consist of mixtures of hæmatite and chamosite with some siderite, as compared with the mixture of magnetite and chamosite in the Welsh ores. They are supposed to result from the direct deposition of iron-ores both as silicate and as oxide, possibly, in part at least, through the influence of bacterial action. A certain amount of penecontemporaneous oxidation leading to the production of additional hæmatite is thought by Mr. Hayes to have resulted through the action of boring algae. The possible part played by bacterial action in the formation of iron-ores has been fully discussed by Dr. E. C. Harder, who has summarized the evidence for the precipitation of iron as oxides, sulphides, etc., according to the oxidizing or reducing nature of the surroundings. It is, therefore, easy to understand that a slight lessening of the oxidizing nature of the medium would lead to the production of magnetite instead of hæmatite. A further lessening would lead to the production of a sulphidic ore.

The source of the iron is not far to seek, since the ore-bed is underlain by a great thickness of pillow-lavas. The frequent association of iron-ore beds with pillow-lavas is sufficiently well-known to need no further comment. Microscopical examination shows some of the lavas of the Lower Basic Group to be unusually

in iron as magnetite.

(6) The Llyn-y-Gader Mudstones and Ashes.

The Llyn-y-Gader Group overlies the oolitic iron-ores, and consists of some 500 feet of mudstones with associated ashes. As developed around Llyn y Gader itself the group shows three well-marked stages: lower and upper mudstone stages, separated by a massive ash.

(i) The lower mudstone stage consists of about 100 eet of cleaved blue-grey mudstone, which rests on the ironstone below. The dark mudstones associated with and overlying the iron-ores become paler upwards, and pass insensibly into mudstones which

¹ 'The Wabana Iron-Ore of Newfoundland' Geol. Surv. Canada, Dept. of Mines, Mem. 78, 1915.

² 'Iron-Depositing Bacteria & their Geologic Relations' U.S. Geol. Surv. Profess. Paper No. 113, 1919.

Q. J. G. S. No. 324.

are classed with the Llyn-y-Gader Group. Stratigraphically, therefore, the ironstone itself should be regarded as belonging to, and defining the base of the Llyn-y-Gader Group; it has been

separately treated, purely for convenience of description.

The lower mudstone-band normally determines the position of a narrow boggy hollow immediately south of the ironstone, as at Cross Foxes and Bwlch Coch. But often the beds crop out on steep slopes determined by overlying intrusions, under which conditions they are frequently well exposed. For example, they are well seen below the great semicircular moraine that hems in Llyn y Gader, also along the steep slope below the northern front of Mynydd Moel, and at numerous other points.

The lower mudstones are usually unfossiliferous, probably owing to the intense cleavage, but on a little scarp below the eastern moraine of Llyn y Gader they yielded numerous badly preserved graptolites, some of which were referable to Glyptograptus tereti-

usculus.

(ii) The massive ash succeeds the lower mudstone quite abruptly. The ash varies in thickness from 40 to 100 feet, and it includes both fine-grained and coarse-grained types. The most characteristic type is a massive thickly-bedded, but laminated rock, composed of broken porphyritic felspars set in a fine-grained matrix. Associated with this felspathic type are bands of fine-grained adinole-like ash, also agglomeratic bands with abundant fragments of vesicular rocks derived from spilite-lavas. The whole assemblage is very similar to some of the ash-bands intercalated in the Lower Basic Group. By virtue of its occurrence at a definite level above the iron-ore this ash proved a most useful horizon in mapping, and in unravelling the tangle of volcanic and intrusive rocks.

The great granophyre-sill of Llyn y Gader is intruded above this ash-band, and the sill keeps its position above the ash with remarkable regularity from Mynydd Moel to beyond Cyfrwy.

(iii) The upper mudstone stage, as developed on Pen y Gader above the granophyre-sill (Pls. XXXIV & XXXV), consists of about 400 feet of strata (exclusive of a dolerite-sill 350 feet thick, which is intruded about 300 feet above the granophyre). The beds are mainly cleaved blue-grey mudstones, rather greyer and more flaggy than the darker mudstones below. They are often banded, owing to the presence of gritty layers, and at certain levels (especially in the 100 feet of beds above the dolerite) they contain numerous intercalated bands of fine-These bands vary from half grained adinole-like material. an inch up to 3 or 4 feet in thickness. Most of them consist of fine-grained, pale, porcellanous-looking material; but others are blue and almost vitreous in appearance, and are typical adinoles. All the beds have suffered more or less contact-alteration, owing to proximity either to granophyre or to dolerite, so that the slates are often spotted. Nevertheless, the adinole-like bands cannot be ascribed solely to contact-action, for their interbanding with ordinary slaty material is too intimate and too often repeated. They must be due to original differences in composition of the sediments, and they simply represent altered ashy material.

Although best exposed on the northern precipice of Pen y Gader, the beds may also be studied above Llyn Aran below the northeastern slopes of Mynydd Moel, where the strata abut against the

granophyre.

The grey flaggy slates of the upper mudstone stage have so far failed to yield fossils. Owing to cleavage and to the frequent spotting due to contact-alteration, conditions are rarely suitable

for the preservation of fossils, even if originally present.

The Llyn-y-Gader Group, and especially its upper mudstone stage, suffers remarkable changes in thickness as it is traced through the district, and these changes appear to be connected in some cases with the disposition of the north-and-south cross-folds (see below, p. 577). For example, the group attains its maximum thickness in the Llyn-y-Gader and Tyrau-mawr Synclines, but is greatly reduced when it crosses the Llyn-Aran Anticline, and the anticlinal areas east and west of Tyrau-mawr. This apparent connexion between variation in thickness and the distribution of the transverse folds suggests that the folding movements were already in operation during the deposition of the strata, resulting in maximum deposition in subsiding (synclinal) areas.

(7) The Upper Basic or Pen-y-Gader Group.

The Llyn-y-Gader Mudstones are followed by the Upper Basic Group, the third of the four main volcanic groups on Cader Idris. The Upper Basic Group presents two rather different facies, when followed along the Cader Idris range. The more typical facies, which is developed along the central and eastern portions of the range, consists essentially of spilitic pillow-lavas with only subordinate ash-bands, whereas the western facies consists dominantly (and often exclusively) of pyroclastic material. It will be convenient to consider first the eastern and typical facies, as seen on Pen y Gader itself.

(a) The eastern facies.—Both lower and upper limits are well defined lithologically. The group begins with a massive ashband about 100 feet thick, which is well displayed at the summit of Pen y Gader, where the ash forms a capping to the great cliff above Llyn y Gader (Pl. XXXV). The distinctive character of the ash enables us to follow it from the summit along the strike for a considerable distance in both directions. The band is pale below and dark above; it consists essentially of massive well-jointed beds, composed largely of broken felspars set in a laminated dark matrix, making a rather handsome and very characteristic rock. It is a curious feature throughout all the volcanic rocks of Cader Idris

that, if a rock contains abundant porphyritic felspars, it is almost

certainly an ash and not a lava.

Above the ash comes the main mass of the Upper Basic Group, consisting almost entirely of pillow-lavas, with only one or two minor ash-bands and an occasional thin chert-band. The Upper Basic Group differs from the Lower Basic Group in many respects. and the two sets of basic rocks can be readily distinguished in the field, quite apart from their stratigraphical position. The bands of slate, and of laminated and agglomeratic ashes, that play so considerable a part in the Lower Basic Group, are not found in the Upper Group, so far as its eastern facies is concerned (except in the basal ash-band mentioned above). The lavas of the two groups are also easily distinguished, both in the field and under the microscope. Those of the Upper Group are much more uniform, and they nearly always show distinct pillow-structure, whereas those of the Lower Group usually are only pillowy along their upper surfaces. Again, the lavas of the Upper Group are not so coarsely vesicular as those of the Lower; also the material between the pillows in the younger group is more distinctly cherty, and no great masses of purely slaty material are to be found. Under the microscope the rocks are seen to be typical spilites, and to show much less variation in texture than the lower set of pillow-lavas.

The lavas of the Upper Basic Group form the actual summit of Cader Idris, and occupy the rough dip-slope which descends to Llyn Cau. As a result of weathering at these exposed altitudes the characteristic features of the lavas are well seen, and I know of few localities where pillow-lavas may be better studied. The pillow-structure was noticed by Sir Andrew Ramsay, while Sir Archibald Geikie 2 compared the rocks in appearance with the Arenig pillow-lavas of Girvan, and was the first to suggest that they might be of extrusive origin. I recorded their identity with

spilites in 1913.3

From Pen y Gader eastwards the lavas can be followed for about a mile along the rugged dip-slope above Cwm Cau, until they disappear against the great granophyre-mass of Mynydd Moel. The lavas reappear beyond the intrusion, but now on the scarp-face above Llyn Aran. They can be followed along the scarp for about 2 miles, until they run down gradually beneath the superficial deposits of the great fault-valley. Ramsay 4 recognized the distinctive character of the band, and described its occurrence on the opposite side of the fault-valley, where the repetition causes the rocks to reappear on the desolate slopes near Hafod-oer, beyond the eastern boundary of the map (Pl. XXXVII).

One or two dolerite-sills appear to be entangled with the pillow-

¹ 'The Geology of North Wales' Mem. Geol. Surv. vol. iii, 1st ed. (1866)

² 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 184.

³ A. H. Cox & O. T. Jones, 'Pillow-Lavas in North & South Wales' Rep. Brit. Assoc. (Birmingham, 1913) 1914, p. 495.

^{4 &#}x27;The Geology of North Wales' Mem. Geol. Surv. vol. iii, 1st ed. (1866) p. 32.

lavas on the dip-slopes above Cwm Cau, and again on the scarp between Llyn Aran and Geu Graig. The rocks have not, however, been separately mapped, owing partly to the difficult nature of the ground, and partly to the difficulty of distinguishing between intrusive and extrusive rocks in the field. The local failing of pillow-structure is no certain guide. A vesicular character is also no guide, since the intrusions are usually vesicular towards their margins. Similarly, the texture is not always a safe guide, especially if the intrusion is small. If the intrusion is fairly large, the texture may become ophitic; but this is usually only revealed by microscopic examination. The detailed mapping of the often intricate boundaries between the two sets of rocks did not seem to justify the labour involved. Therefore some of the intrusions are not shown on the map (Pl. XXXVII).

(b) The western or Tyrau-mawr facies of the Upper Basic Group.-West of Pen y Gader the pillow-lavas and underlying ash can be followed for about a mile, striking into a drift-covered hollow. Then the group appears to run up the grass-covered dip-slope, and so gains the scarp-slope of Tyrau-mawr. The facies has now changed to one consisting almost entirely of pyroclastic material, with few if any lavas. The base of the group is made up of the same massive felspathic ash, pale below and dark above, as in the eastern facies. Above this come ashes of a variety of types, which succeed one another rapidly. They include fine-grained rocks, with a characteristic jointing recalling the jointing of the granophyre. With this fine-grained type are associated beds of agglomeratic material that weathers exactly like a pillow-lava, being vesicular and sometimes showing traces of pillow-structure. This represents either a spilite-agglomerate or a spilite-flow-breccia: the former seems the more likely, in view of the comparatively small thickness of the bed and its intercalation among undoubted ashes. Above follow more ashes of variable character, including both fine- and coarse-grained types, with some further repetition of spilite-agglomerate. Finally, as one ascends the group, the ashes become rapidly less massive and, assuming a sheared aspect, pass up into cleaved mudstones.

This ashy group is invaded by at least two thin dolerite-sills which usually follow the bedding very regularly. Since these sills are quite thin where seen on the scarp-slope, they are fine-grained and more or less vesicular throughout. This adds to the difficulties of ascertaining whether any true spilite-flow is here present.

This series can be followed along the northern front of Tyraumawr until it passes beneath the granophyre towards Llyn Cyri. The same beds emerge from beneath the granophyre near Ffordd Ddu. They are there brought into close proximity to the oolitic iron-ore, suggesting that a part of the underlying Llyn-y-Gader Group is cut out by strike-faulting. From Ffordd Ddu the beds slant obliquely across the scarp-face of Braich Ddu, and are eventually lost on the grassy slopes beyond, save for occasional isolated exposures.

(8) The Llyn-Cau Mudstones.

The Upper Basic Group is succeeded by a thick group of blue-grey mudstones, well seen above Llyn Cau and also along Geu Graig. Where the top of the Upper Basic Group is formed of pillow-lavas, as between Llyn Cau and Geu Graig, the change in the rock-types is quite abrupt. But, where the top of the volcanic group is ashy, as along Tyrau-mawr, there is a kind of rapid transition from massive ashes, through sheared ashy slates, into normal mudstones.

The mudstones have been considerably affected by cleavage, and in the lower part of the group the bedding has been entirely obliterated. Towards the top the incoming of a certain amount of ashy material serves to reveal the bedding, and ushers in the

volcanic rocks of the Upper Acid Group.

Fossils are extremely scarce, possibly owing to the strong cleavage, but numerous specimens, all referable to Glyptograptus teretiusculus, were obtained west of Tyrau-mawr, close to the point where the path from Arthog to Cader Idris passes from the scarp on to the dip-slope of Tyrau-mawr. These fossils were from

beds quite low down in the Llyn-Cau Group.

The upper beds of the group become ashy and full of broken felspars. There are several alternations of such ashy beds with beds almost free from ash, until eventually the mudstone group passes rather gradually into the overlying Upper Acid Group. Although the change from the sedimentary to the volcanic group is actually in the nature of a transition, yet a fairly sharp line may be drawn in the field at the level where the strata cease to be dominantly argillaceous, and become dominantly pyroclastic.

(9) The Upper Acid or Craig-y-Llam Group.

The Upper Acid Group is the highest of the four volcanic groups of Cader Idris. It consists of a complex series of ashes and lavas of intermediate to acid composition, with occasional intercalations of slaty material. Although the group is here termed an acid group, and stands indeed in strong contrast with the thoroughly basic character of the Lower and Upper Basic Groups, it should be noted that this Upper Acid Series is not so markedly acidic as the Lower Acid or Mynydd-y-Gader Group. The Lower Group includes nothing but the most extremely acid type of rhyolite, whereas many of the eruptive rocks of the Upper Acid Group are scarcely acid enough to be described as rhyolites. They are perhaps best regarded as rather acid and silicified keratophyres. Such rocks would formerly have been looked upon as acid andesites; but their affinities are obviously rhyolitic, and every transition may be found from these 'acid andesites' to true rhyolites. Nevertheless, thoroughly acid rocks, of the type that assume the thick cream-coloured or white crust characteristic of the more acid rhyolites, are in the minority.

All these rocks have been more or less affected by a silicification which has helped to disguise their original character. The silicification is so uniform that it is probably in the nature of a 'juvenile' change. A similar silicification has affected the accompanying ashes, and has rendered it difficult, if not impossible, to separate some at least of the pyroclastic rocks from the lavas. This is especially the case where the ashes consist of massive beds composed entirely of comminuted rhyolitic dust. The original structures may be entirely destroyed by silicification.

Further difficulty in separating pyroclastic rocks from the lavas arises from the fact that some of the lavas show a flow-structure which closely simulates the rough lamination characteristic of many of the ashes. Yet another difficulty arises from the autobreceiation of some of the lavas, which cause them to assume the appearance of agglomerates. For example, one rock, which for a long time I considered a typical coarse agglomerate, was found eventually to have, locally, a nodular structure developed in its matrix; it then betrayed itself as a nodular rhyolite enclosing angular fragments of non-nodular andesitic material. Since most of the rocks are not acid enough to develop a nodular structure, this criterion cannot often be used.

A general sequence, which holds good throughout the district, can be traced within the Upper Acid Group; it thus is possible to recognize certain subdivisions: for example, nodular rhyolites, massive rhyolites, 'rough-weathering' rocks, and flaggy ashes. But the remark made by Prof. W. G. Fearnsides concerning the very similar rocks of Arenig Mountain, that

'.... there are no very sudden changes in the character of the material, and what may appear to be good mappable lines at one place usually lapse into a maze of similarities within a very few hundred yards along the outcrop' ('The Geology of Arenig Fawr & Moel Llyfnant' Q. J. G. S. vol. lxi, 1905, p. 625)

may equally be applied to the Cader Idris rocks. For these reasons it appeared to me a waste of labour to differentiate the outcrop as represented on the map.

Three, or perhaps four, more or less clearly-defined subdivisions can be recognized. The general sequence in descending order is

as follows :---

Talyllyn Mudstones.

(d) Well-bedded flaggy ashes.

(c) Massive ashes and agglomerates, with possibly some autobreceiated lavas. Weathering generally yields knobbly uneven surfaces, often showing irregular lamination.

(b) Very massive 'andesitic' ashes and (?) lavas, with strong joints causing vertical chimneys in the cliffs. Occasional shaly partings are intercalated between the massive beds. This division makes more than half the total thickness of the Group.

(a) Rhyolitic lavas, often nodular and sometimes autobrecciated, with intercalated bands of ashy slate and silicified mudstone. At the base,

ashy slates passing downwards into Llyn-Cau Mudstones.

The most imposing and most continuous exposure is that which forms Craig Cau, and the ascending succession may be readily examined by following round the crest of the precipices that descend to Llyn Cau, and then continuing to the head of Cwin Ammarch.

(a) The volcanic series begins with ashy slates, which are passage-beds from the Llyn-Cau Slates below. Then come rhyolitic lavas, the lowest of which are usually nodular. The nodules are not so large as in the nodular rhyolites of the Lower Acid Group of Mynydd y Gader. Usually they are about the size of a

pea, rarely approaching the size of a small marble.

On the precipice above Llyn Cau a rhyolite with scattered nodules shows pronounced autobrecciation, and closely simulates an andesitic agglomerate, the nodules being confined to the matrix, while the included fragments, which range up to 6 inches or more in diameter, show no trace of any nodular character. Nodular rocks are found at the corresponding horizon at many other localities over a distance of 8 miles, from Craig y Llyn and Craig Tyn-y-Cornel on the west to Geu Graig on the east.

(b) The andesitic ashes and (?) lavas.—Above the nodular rhyolites comes the main mass of andesitic to rhyolitic ashes and lavas, with occasional partings of silicified mudstone. The whole group is so affected by silicification that it becomes difficult to say how far true lavas are represented. Individual bands are often exceedingly massive, and show a strongly marked master-jointing. These massive beds are sometimes very uniform, or they may show indications of a lamination, usually apparent only under certain conditions of weathering, or sometimes also in thin section. They are nearly all composed of exceedingly line-grained material, which (in some cases) clearly is comminuted volcanic dust practically free from normal sedimentary matter. As a rule, the original structures are more or less completely obscured by silicification.

Other examples of these massive beds appear from microscopic examination to be acid andesites or rhyolites highly silicified, and exhibiting micropecilitic texture. The micropecilitic areas enclose multitudes of tiny felspar-laths, while phenocrysts of felspar occur

sparingly.

(c) The massive smoothly-jointed rocks pass upwards, without any clear dividing-line, into another set of massive rocks. These latter are again fine-grained, but weathered surfaces are often rough and knobbly, with an irregular lamination or flow, so that the rocks at first sight recall coarse agglomerates. Actually, however, no clear distinction can be made between the resistant 'nodular' masses and the enclosing less resistant matrix. The rudeness of the structures often suggests that one is dealing with the slaggy surface of a flow. The microscope affords little help; it simply reveals the rocks to consist of uniformly fine-grained

material, highly silicified, and presenting no trace of any structure that would characterize the rocks definitely either as lavas or as ashes. These rocks form a considerable spread west of the summit of Craig Cau.

(d) The top of the Upper Acid Group is formed by a small thickness of well-bedded flaggy ashes. The flaggy character of these beds becomes more pronounced upwards. Again the rocks are fine-grained, intensely silicitied, and practically devoid of ordinary sedimentary material. The flaggy ashes are overlain on Craig Cwm Ammarch by a single bed, 6 to 8 feet thick, composed of coarser pyroclastic material, above which there is a very abrupt change in the lithology, and the Talyllyn Mudstones appear quite suddenly.

These highest ash-beds contain locally strings and patches of galena, and trials have been made at Castell y Bere in the Dysynni

Valley, and above the northern end of Talyllyn Lake.

The outcrop of the Upper Acid Group terminates against a powerful fault (p. 583) in the Lower Dysynni Valley, opposite the Bird Rock. The fault evidently continues down the Dysynni Valley towards the sea, cutting out the volcanic rocks all the way, thus explaining the curious and sudden disappearance of a volcanic band that can be followed right round the Harlech Dome.

(10) The Talyllyn Mudstones.

The topmost ashes of the Upper Acid Group are succeeded abruptly by a thick sedimentary series—the Talyllyn Mudstones. These begin with a small thickness of flaggy beds, that pass upwards into a great series of blue-grey banded mudstones which occupy most of the ground on both sides of the Talyllyn Valley. This series has not, as yet, been subdivided. The beds are highly cleaved, much affected by minor folding, and are repeated by the great Talyllyn Fault, so that their outcrop is very considerable.

Towards the eastern part of the district the beds have been studied by Prof. W. J. Pugh on Craig y Llam and Mynydd

Ceiswyn. He estimates their thickness at 4000 feet.

The main mass of the mudstones has proved to be remarkably unfossiliferous. The only fossils so far obtained were found in the flaggy beds that constitute the base of the mudstone group. On Craig Cwm Ammarch the flags yielded Amplexograptus arctus and Glyptograptus teretiusculus var. euglyphus in some abundance, despite the somewhat unpromising lithology.² In the area subsequently examined by Prof. Pugh the corresponding beds (the Ceiswyn Mudstones) failed to yield identifiable fossils, probably owing to the intensity of the cleavage.

² A. H. Cox & A. K. Wells, Rep. Brit. Assoc. (Manchester, 1915) 1916,

p. 425.

 $^{^{1}}$ 'Geology of the District around Corris & Aberlle fenni ' Q. J. G.S. vol. lxxix (1923) p. 515.

The Talyllyn Mudstones are succeeded, in the area described by Prof. Pugh, by the graptolitic shales of the Nod Glas slate-vein with *Dicellograptus clingani*, etc., and then by the various slates and mudstones that represent the higher portion of the Bala Series. In all this great mass of mudstones there is no sign of any volcanic rocks. Thus, in this part of Wales, the volcanic rocks end quite suddenly with the Upper Acid Group, low down in the sub-zone of *Amplexograptus arctus*, and there were not even spasmodic outbreaks after the close of the main episode.

The nature of the junction between the Talyllyn Mudstones and the underlying volcanic rocks is a matter of some interest. It has been suggested that the volcanic accumulation of Arenig Mountain persisted for some time as a subaërial cone or island, and that there is a gap between the highest volcanic rocks and the overlying conglomeratic limestones (Derfel Limestone). In the English Lake District it has been shown that the Borrowdale Volcanic Series is succeeded unconformably by the Coniston Limestone Series. Accordingly, the upward limit of the volcanic rocks of Cader Idris was especially studied, in order to ascertain whether there is a break or a transition from the volcanic to the

sedimentary rocks.

As already mentioned, the change from volcanie rocks to the overlying mudstones is certainly abrupt. But, at several localities where the junction is well-exposed, there seems to be evidence of an actual transition from one set of beds to the other. For example, on Craig y Llam the junction is well seen in Nant y Benglog. There the topmost ashes of the Upper Acid Group suddenly become flaggy and well-cleaved, and intercalations of hard shale appear in the ashes, which thus pass into the overlying Talvllyn Mudstones. The change is rapid, as the transition-beds are only about 4 feet thick; but it appears to be a true transition. Similarly, in the western part of the district the junction shows some evidence of a transition. Along the eastern margin of the Bird Rock mass the highest volcanic rocks are flaggy, fine-grained, and sometimes banded ashes, succeeded rather abruptly by hard rubbly slates with thin ashy intercalations. The junction here is more abrupt than on Craig y Llam, but still it appears to be a true transition.

On Craig Cwm Ammarch the junction is particularly well displayed. The fine-grained flaggy ashes that constitute the highest volcanic rocks are overlain by a single bed of coarser ashy material. This coarse bed is immediately followed by the mudstone series, the lowest beds of which are rather flaggy and hard, and evidently contain much finely divided ashy material; it was from these beds that the graptolites were obtained (p. 567). The flaggy character becomes less pronounced upwards, and the strata soon assume the

¹ W. G. Fearnsides, 'Geology in the Field' Geol. Assoc. vol. ii (1910); p. 797.

² J. F. N. Green, Proc. Geol. Assoc. vol. xxvi (1915) p. 218.

normal appearance of banded argillaceous mudstones, while the cleavage becomes increasingly pronounced. Despite the fact that the lowest mudstones present this flaggy appearance and contain much fine-grained detrital ashy material, they have nothing in common with the flaggy ashes that form the top of the volcanic rocks; here is no actual transition between the two sets of strata. The presence of a single bed of coarse material intervening between the two groups might at first be considered as a possible indication of a stratigraphical break at this point, with the coarse bed representing the lowest stratum of a new group. But, since there is not the slightest indication of any passage from the coarse bed into the fine-grained mudstones, it would seem more natural to connect the coarse ash-bed with the fine-grained ashes below, than with the mudstones above. This being so, it cannot be said that there is in this section any definite evidence of a stratigraphical break, apart from the very sudden change in lithology.

III. THE INTRUSIVE ROCKS.

(a) The Dolerites.

Basic intrusions are represented (i) by a regional series of gabbroid dolerites, and (ii) by a series of spilitic dolerites; but the two series are petrographically so closely allied that it is often difficult to make a distinction.

(i) The gabbroid dolerites: field relations.—Sills and laccolitic masses of dolerite are abundant in all the formations, from the Upper Basic Group downwards. In most cases, their position seems to have been determined by the presence of some particularly massive band among the stratified rocks. Thus the largest intrusions are found: (1) among the rhyolites and ashes of the Lower Acid Group; (2) in or immediately below the Cefnhir Ashes; (3) in the Llyn-y-Gader Slates below the Upper Basic Group; and (4) among the lavas and massive ashes of the Upper Basic Group. But not a single dolerite has been found above the Upper Basic rocks, a fact which appears to set an upward limit to the age of the basic intrusions. The intrusions become more numerous eastwards, and the larger masses also tend to thicken eastwards: that is, in the direction in which the different volcanic groups also thicken. This eastward thickening of the intrusions appears to have attained its maximum within the district mapped.

The complex relations of the great intrusive mass of Mynydd y Gader to the neighbouring stratified rocks have been described in considerable detail by Mr. Lake & Prof. Reynolds.¹ They have shown that, while part of the mass behaves as a sill inclined equally with the stratified rocks, another part acts as an almost horizontal cake, and transgresses northwards over the highly

inclined strata on to lower stratigraphical horizons. Thus, large areas of stratified rocks may be concealed beneath the dolerite.

Similar relations seem to hold for others of the greater basic intrusions of the area: for, in a number of instances, the intrusion appears to introduce an apparent gap in the stratigraphical succession, and in most cases the absence of the sedimentary beds is not to be explained by faulting along the margin of the intrusion,

nor by faults occupied and concealed by the intrusions.

Cases have also been observed of the opposite relationships, where sedimentary rocks are transgressively underlain by a big intrusion. For example, in the Aran Valley immediately north of the area mapped, an extensive area of Ffestiniog Beds is found to be highly contact-altered, although at some distance from a visible doleritic outcrop, However, the Aran stream has cut down to a dolerite intrusion that underlies the stratified rocks and strikes at right angles to their strike, while the plane of contact dips 40° eastwards as against a stratal dip of 50° south-eastwards.

It is, however, only the greatest intrusions that sometimes act transgressively, and even these more frequently behave as true sills dipping in accord with the stratified rocks, while the smaller

intrusions behave always as true sills.

The Mynydd-y-Gader dolerite is mostly rather fine-grained, considering the great size of the intrusion, and there are some indications that it represents a multiple intrusion.

(ii) The spilitic dolerites.—Quite apart from those dolerites that act as larger or smaller sills in all the horizons from the Upper Basic Group downwards, there is a set of basic intrusions only found within the limit of the Lower Basic Group. It is often a difficult matter to distinguish these local intrusions from the regional dolerites on the one hand, and from the spilitic lavas on the other, either in the field or under the microscope. The only guide is the mode of occurrence. The local intrusions behave as sills, but differ from the regional dolerites, in that individual intrusions are more distinctly lenticular, seldom exceeding a mile in length, and more usually extending only for about a quarter or half a mile along the strike.

The thickness of such an intrusion may reach as much as 200 feet, but is usually much less. The biggest examples are seen in the upland valley between Mynydd y Gader and Mynydd Moel. The rocks in these intrusions are often characterized by a pronounced polygonal jointing. In nearly all their features, columnar jointing, vesicular appearance, and in petrographic characters, the rocks of these local intrusions are almost indistinguishable from the coarser portions of some of the thick spilitic

lavas that accompany the intrusions in the field.

The intrusions are so similar to the spilites, and are best developed where the spilites attain their maximum thickness, that it is impossible to resist the conclusion that these local intrusions were intimately connected with the vulcanicity, and that they represent spilitic material that failed to reach the actual surface.

(b) The Granophyres.

Two great granophyre-sills occur within the area. The higher one is well known by reason of the fine exposures on the cliffs of the northern face of Cader Idris.

The Crogenen intrusion.—The lower mass has been termed 'the Crogenen intrusion'. It has a double outcrop, owing to repetition by the Gwernan Fault. The northern outcrop of this intrusion was described in detail in the Arthog paper (p. 284). The outcrop south of the Llvn Gwernan Valley is in two portions: a small one at Penrhyn-gwyn in the east, and the main outcrop farther west, below Tyrau-mawr and Craig y Llyn. At Penrhyngwyn only the upper part of the intrusion is visible below its roof of Bifidus Beds with associated dolerite. This isolated outcrop is apparently due to one of the small anticlinal cross-folds (p. 577). The main portion of the southern outcrop needs little description. Despite the wide outcrop, exposures are few, and limited to the upper parts near the roof. Other parts are covered by scree on the steeper slopes, or by drift and peat on the lower ground, as below Craig y Llyn. The western termination of the sill is, however, well displayed in the cliffs on the shoulder of Braich Ddu, where the exposures furnish a diagrammatic illustration of the tailing-out of a laccolite.

In the description of the northern outcrop (Arthog paper, p. 284) it was shown that, while the intrusion acts generally as a sill, there is a steady transgression into higher beds from north to south and from east to west. This transgression is also continued in the southern outcrop, with the result shown in tabular form below:—

North.

(strata dip southwards.)

West.

East.

Crogenen.

Gelli-lwyd.

floor—Cefn-hir Ashes.

floor-Tremadoc Beds.

roof—Lower Basic Group.

roof—Lower Acid Group.

Gwernan Fault.

below Craig y Llyn. floor—Lower Basic Group. roof—Llyn-Cau Slates.

Penrhyn-gwyn. floor—*Bifidus* Beds roof—*Bifidus* Beds.

South.

The basic marginal modifications present along both the upper and the lower margins of the northern outcrop were fully described in the Arthog paper (p. 295). Similar modifications are developed in the southern outcrop, and are especially well seen at Penrhyngwyn above the farm, also in the western bank of the neighbouring ravine. Westwards the basic margins become less pronounced, just as in the case of the northern outcrop, until at the western termination of the sill on Braich Ddu, the only sign of abnormality is the marked development of spherulitic structures (see Arthog paper, p. 294).

The Llyn-y-Gader sill.—The higher of the two great sills forms the most conspicuous feature of the Cader Idris range, and as such has been noted by all previous writers. It is consequently so well known that a detailed description here is unnecessary. It forms the great line of northward-facing cliffs from Cyfrwy past Llyn y Gader to Mynydd Moel (Pl. XXXIII), and along this stretch of nearly 3 miles it occupies the actual summit-ridge, except on Pen y Gader itself, where the overlying strata (the Llyn-y-Gader Mudstones and the Upper Basic Group) are brought down by a syncline (Pl. XXXIV). The rock is noted for its perfect columnar structure, best seen perhaps on Cyfrwy (Pl. XXXV). Along the main part of its course the sill keeps with wonderful regularity to the junction between the Llyn-y-Gader Ash and the overlying slates (divisions ii & iii, p. 560).

The terminations of the sill, however, merit some further notice, as some confusion has existed concerning this matter in the past. The mode of termination is utterly different at the two ends. 'The westward termination of the great sill dwindles away to a blunt point (see below, p. 578), whereas the eastward termination is a great swollen mass of laccolitic nature, which occupies the core of an anticline. Near Llyn Aran the intrusion suddenly changes its course, turns southwards, and cuts across the strata almost at right angles. It penetrates the whole of the Upper Basic Group, and invades the rhyolites of the Upper Acid Group. The outcrop of the Upper Basic Group, which on the west occupies the dipslope above Llyn Cau, is completely interrupted by this southern projection of the granophyre mass, the lavas reappearing eastwards on the scarp-slope above Llyn Aran. The junctions are not faults, as shown on the Old Series 1-inch map. Faulting would offer a simple explanation of the displacement of the outcrops; but there is conclusive evidence, both along the upper or western margin and along the lower or eastern margin, that the junctions are normal intrusive contacts.

The evidence that the junctions are not faulted is twofold: there is first the irregular course of the junctions, which sometimes cross from one gully to another, and then back again; secondly, there is the presence of marginal modifications of the granophyre along the course of the junctions, proving that nothing has been

faulted out.

This swollen mass apparently covers the point of origin of the granophyre. The intrusion evidently rose in laccolitic fashion along the core of a north-and-south anticline, and it further pushed its way through the strata on one side (west) of the anticline to form a great sill-like prolongation, which gradually dwindled away as it approached the synclinal axis of Tyrau-mawr.

The anticline, however, did not grow rapidly enough to allow

of the formation of a perfect laccolite, consequently some of the junctions are those characteristic of a boss. Hence the rapid transgression along the eastern boundary, which gives the mass, as viewed from the east, the appearance of a boss; hence, also, the manner in which the mass has pushed its way through the Upper Basic Group, instead of actually lifting the volcanic rocks into an arch. The cover of volcanic rocks was lifted to a certain extent, as proved by the abnormal dips on the south-western flanks of Mynydd Moel; it was not, however, lifted intact, because the outcrop does not extend completely round the dip-slope of the laccolite, but is missing for about a third of a mile.

Although the filling of the Mynydd-Moel boss was rapid, it still appears to have taken place in stages, for different parts of the granophyre show a difference in their columnar structure: the boundaries of these subdivisions run parallel to the outer boundaries of the main mass, as if they represent small distinct

intrusions.

This statement as to intrusion taking place in a number of stages does not apply to the westward prolongation of a great sill. The sill, apart perhaps from certain marginal rocks mentioned below, represents a single large intrusion, as proved by the uniformity in the columnar structure visible below Pen v Gader and on Cyfrwy. The boss was partly filled by a number of small intrusions, and then by one large intrusion in which the magma came up so rapidly that it broke through laterally to form the great sill of Cyfrwy, etc.

The intrusion, as a whole, does not show the westward transgression on to higher horizons which is so constant a feature of the Crogenen intrusion (p. 571, ante); but, where arched by the Mynydd Moel anticline, it does show a southward transgression

somewhat similar to that of the Crogenen sill.

Marginal facies.-The Llyn-y-Gader intrusion does not show basic marginal rocks of the type so well developed along both the upper and the lower margins of the Crogenen sill (p. 571, ante). A slight tendency towards the development of a basic margin is apparent along the eastern margin of the mass, and can be seen in the cliffs above Llyn Aran. Also along the south-western margin of the Mynydd Moel mass the rocks are slightly basic; these basic rocks, when chilled, lose all resemblance to the normal granophyre, so that it may even become difficult to separate the chilled modified granophyre from the contact-altered spilitic rocks. Similar basic marginal rocks, full of quartz-veins and aplitic veins, can be studied on the upper margin, half a mile west of Mynydd Moel, at the point where the outcrop is crossed by a small anticline. The overlying slates have been stripped off, revealing the steep pitch in a diagrammatic manner. The development of quartz-veins and aplite-veins in these marginal rocks, and the relationship between the two types of veins is worthy of petrological study.

In a different part of the mass a rather different type of marginal rock appears. The uppermost few feet of the sill, as exposed on some of the cliffs above Llyn y Gader, make a separate and clearly-defined feature. The rock that makes this feature is not basic, but under the microscope is seen to be (if anything) more quartzose than the normal granophyre, and its texture is granular instead of granophyric. There does not appear to be a clear transition from the granular to the granophyric type, and the clear-cut character of the feature suggests at first sight that it is due to a separate intrusive band. This, however, is rather unlikely, but the question is worthy of some further study.

The age of the intrusive rocks was discussed in the Arthog paper (p. 304). Reasons were there advanced for assigning an early Bala age to the intrusions. This conclusion was reached mainly on account of (i) the petrographic similarity of extrusive and intrusive rocks, and (ii) the fact that no intrusive rocks occur above the highest volcanic rocks.

IV. THE TECTONICS.

Some preliminary observations on the general structure of the district were set forth in an earlier section of this paper (p. 543). These may now be amplified with regard to some of the more

important points.

The general strike is determined by the swing of the beds round the southern flanks of the Harlech Dome. The general trend is north-east to south-west, but along the central part of the range the strike is nearly east-and-west. It will be noticed that the changes from the north-easterly to the east-and-west direction, and back again to north-east and south-west, take place quite suddenly. Dips are usually about 40°, but along the ridge of Geu Graig and over a part of the Aran Valley south of Geu Graig, the dip steepens until the strata are vertical.

One striking feature noted on making a traverse across Cader Idris is that, while dips remain fairly constant among the volcanic rocks, so soon as the Talyllyn Mudstones are reached, folding and rolling of the beds at once begin. This effect is, however, possibly more or less local, and connected with disturbances parallel to the

Talyllyn Fault (see below, p. 579).

The structure is complicated by disturbances of various types. These include, arranged in probable order of formation:—

- (i) (a) transverse or north-and-south folds common,
 (b) north-and-south faults less common,
 (ii) dip-faults common,
- (iii) (a) longitudinal, or north-east-and-south-west folds

distribution may be wide,

(b) longitudinal, or north-east-and-south-west faults not common, but widely distributed,

(c) east-and-west faults restricted distribution—
variant of (iii b).

(iv) great north-east-and-south-west shatter-faults.

(ia) The north-and-south transverse folds present some of the most interesting features in the tectonics of the area. They are most conspicuous in the outcrop of the Upper Acid Group, which is made to swing southwards or northwards for 1, 2, or even 3 miles, by each fold, according to whether the fold is anticlinal or synclinal. The smaller examples of the folds are, however, often difficult to recognize, owing to the complications introduced by high relief and the presence of intrusions and faults.

A curious feature of several of these folds is that, while their effects may be very marked in the outcrops of one particular rockgroup, they may be hardly perceptible, or may apparently disappear altogether, in underlying or overlying groups. Examples will be noted below in the case of the Bird-Rock and Pennant Anticlines, which are prominent in the outcrop of the Upper Acid Group, but lose their identity farther north in the outcrops of the lower beds. Yet, still farther north, another set of outcrops may be affected in their turn. For this reason it is impossible to trace all the folds across the country, or to say in every case which fold in one area corresponds with a particular fold in some distant area. In fact, there appears to be a belt of country, extending due westwards from Dolgelley nearly to Arthog, and occupied by the Upper Cambrian and Lower Ordovician rocks, which fails to reveal these folds. Yet the Middle and Lower Cambrian rocks farther north towards the Harlech Dome are again strongly affected.

The apparent sudden disappearance of the folds is not, however, limited to the Upper Cambrian and Arenig belt west of Dolgelley, for similar difficulties occur where attempts are made to trace folds, visible in Silurian rocks, across the outcrop of the Bala beds.

On account of the many complexities introduced by high relief, faults, and intrusions, it is not yet possible to state whether these apparent disappearances of the folds in certain belts of country are deceptive, or whether they are real and due to the folds being arranged in echelon. However, when more details in the surrounding areas are revealed, it will undoubtedly become possible to trace some of the greater folds for considerable distances, and perhaps to connect them with their former continuations across the belts of shatter-faulting.

The difficulty of connecting up the transverse folds in different areas makes it impracticable to state precisely the direction of the axes of plication; but the direction appears in most cases to be nearly due north and south, with occasional swings to a direction a little west of north.

The north-and-south folds are most clearly marked in the west of the district, where the 'wave-length' of the folds, or the distance from crest to crest, is fairly regular, varying from a mile to a mile and a half.

Since these transverse folds traverse a variety of rock-groups of varying hardness, their effect on the form of the ground varies from one locality to another. Sometimes an anticlinal area forms

the lower ground, as, for example, the great hollow of the Upper Arthog Valley along the Pennant Anticline. But, if the anticline happens to bring up resistant rocks, these form the higher ground, and the intervening synclines are occupied by lower ground. Thus, where the Pennant and Bird-Rock Anticlines cross the resistant rhyolitic rocks of the Upper Acid Group, the anticlines form high ground separated by lower-lying synclinal areas, occupied by the

less resistant Talvllyn Mudstones. One curious effect worthy of record is of an anticline causing a structure which, viewed from a distance, might easily be interpreted as due to a syncline. This happens where the Llyn-Aran Anticline crosses the outcrop of the Upper Acid Group, south of Mynydd Moel, and, in so doing, deflects that outcrop southwards in the direction of the low ground along the Talyllyn Fault-valley. The result is that the outerop swings down from high ground on one flank of the fold, to low ground in the axis of the fold, and then up again to high ground on the other flank. The apparent effect is, therefore, that the outcrop sags towards the fold-core. Thus the first impression of the sag, as viewed from the opposite side of the valley, is that it is due to a synclinal fold. But closer reasoning reveals the true interpretation, that the apparent sag is caused by the denudation of a pitching anticline.

The dissection of pitching folds along various planes, in a country of high relief such as Cader Idris, may often result in deceptive effects on outcrops. By altering the plane of denudation across an inclined fold, outcrops can be made to take any desired curve, either concave or convex. In an anticline the curves will have a downward convexity when the inclination of the dissecting plane is less than the angle of pitch, but an upward one when the angle of the dissecting plane is greater than that of the pitch, or when the inclination of the dissecting plane is opposed to that of

the pitch.

Since the same structure can give either a concave or a convex outerop-curve according to the direction of section, it is obvious that there must also be a position where the 'curve' is such that its projection on a map appears as a straight line. This happens when the curvature of the ground-surface and the curvature of the

fold are such that they coincide in vertical section.

Thus it is not surprising that outcrops, as depicted upon a geological map, may fail to reveal the presence of folds, or that belts of country apparently destitute of folds may appear to inter-

vene between belts of obviously folded country.

Such factors may account for the difficulty of tracing some of the folds through particular areas, as, for example, the area west of Dolgelley, where the general slope of the ground is northward and opposed to the southward pitch.

Some comments upon the individual folds may now be made,

beginning with the westernmost examples.

The Peniarth Anticline forms the western boundary of the area mapped. The fold is not well displayed, since most of its length lies through featureless mudstones. It is responsible for the small isolated outcrop of the Upper Acid Group at Garth-fach near Peniarth, and it also defines the western boundary of the Craig Tyn-y-cornel outcrop of the Upper Acid Group. The eastern limb of the fold is in part replaced by a normal fault, which is sufficiently powerful to cut out the whole of the Upper Acid Group near Peniarth-uchaf.

The Tyn-y-cornel Syncline lies east of the Peniarth Anticline. It differs from most of the transverse folds, in that its effects can be followed at intervals from the southern to the northern boundary of the district. At the southern boundary it determines the western limit of the Bird-Rock outcrop of the Upper Acid Group, and is responsible for the crescentic outcrop of the Craig Tyn-y-cornel mass. The effects of the fold are then lost in the slate ground of Esgair Berfa and Trawsfynydd, but become visible again between Arthog and Barmouth Junction in the varied lithology of the Arenig and Llanvirn Series, and are clearly displayed in the synclinal curves of the ridges as viewed from Barmouth Junction.

The Bird-Rock Anticline is complementary to the Tyn-y-cornel Syncline. It is responsible for the southward projecting volcanic mass of the Bird Rock, where the core of the anticline forms high ground by virtue of the resistant nature of the volcanic rocks, which here occupy the nose of the fold. Northwards across the Dysynni Valley the core of the fold brings up the underlying soft Llyn-Cau Mudstones which form a valley, with the resistant volcanic rocks on either flank.

The Nant-Caw Syncline brings down the soft Talyllyn Mudstones between the resistant volcanic rocks, and forms the deep hollow of the Nant Caw. Farther north, the syncline appears to have put a limit to the westward extension of the Crogenen granophyre, in a manner that suggests that the compression, along what was to be the synclinal axis, was already evident at the time of the granophyre intrusion.

The Pennant Anticline is responsible for the southward projection of the volcanic outcrop of Mynydd Pennant, and it seems to have been the determining factor in forming the hollow which was ultimately to become the corrie of Llyn Cyri. Its northward extension along the upper Arthog Valley is apparent from the map.

The Tyrau-mawr Syncline resembles the Peniarth and Nant-Caw Synclines in causing a hollow where it lets down Talyllyn Mudstones between the volcanic rocks on the flanks of the fold. Farther north it has set a western limit to the extension of the Llyn-y-Gader granophyre in exactly the same way as the Nant-Caw Syncline limited the Crogenen granophyre (p. 572).

The Ysgiog Anticline is responsible for the southward projection of the outcrop of the volcanic rocks onto Craig Ysgiog. Northwards it becomes less marked, as its effects are masked by the high relief.

East of this fold come a number of folds of small amplitude, but having the usual wave-length of about 1 mile. A synchinal deposition is apparent in the cliff of Pen y Gader, as seen from the north (Pl. XXXIV). But, in this case, the outcrops have been modified by corrie-formation, which of itself, in combination with the general southward dip, would suffice to produce an apparent sag in the outcrops. Therefore, the apparent axis may not coincide exactly with the true axis. A small anticline half a mile farther east is referred to on p. 573.

The Llyn-Aran Anticline is a more important fold, and its effects can be traced throughout the district. Its curious action, in producing an apparent synclinal sag in the outcrop of the Upper Acid Group above Minffordd, has already been discussed. Farther north this fold determined the point of uprise of the Mynydd Moel-Llyn y Gader granophyre, and it is along the core of the anticline that the intrusion spreads southwards in a boss-like manner. The effects of the fold are visible in the outcrops round Llyn Aran, also in the Ffestiniog Beds with their attendant sills.

East of this prominent anticline are other minor folds, including a syncline south of Geu Graig, with its complementary anticline just along the eastern boundary of the area mapped.

Age of the north-and-south folds. - The north-andsouth folding seems to have been in operation over a considerable period of geological time, for there is evidence of movement at at least four distinct periods, namely:—(1) post-Cambrian but pre-Arenig; (2) prior to, (3) during, and (4) subsequent to the

eruption of the intrusive rocks.

(1) Evidence for pre-Arenig movement is seen in the Llyn-Aran Anticline, in which the Upper Cambrian strata show the anticlinal arrangement much more clearly than do the Arenig rocks. It is, moreover, significant that only in this anticline are the Ordovician Basement Beds in contact with Ffestiniog Beds. Elsewhere the Basement Beds are usually in contact with Tremadoc Beds.

(2) Evidence for movement during the Ordovician Period. but prior to the intrusions, was adduced in the Arthog paper (p. 307), where it was shown that doleritic intrusions were not affected by the folding to the same extent as the neighbouring sedimentary formations. Some further evidence for inter-Ordovician movement is furnished by the manner in which the folds seem to have affected sedimentation within the Llyn-y-Gader Group, giving a maximum deposition in synclinal areas and a minimum in anti-

clinal areas (p. 561, ante).

(3) Evidence that the movements were active during intrusion is found in the relation of the Mynydd-Moel granophyre to the Llyn-Aran Anticline. Further evidence is found in the manner in which transverse folds have set a limit to the westward extension of the granophyre-sills. The Crogenen granophyre dies away as it enters the Nant-Caw Syncline; similarly the Llyn-y-Gader granophyre tails away as it enters the Tyrau-mawr Syncline. The manner in which the two intrusions tail out westwards is almost identical. That both intrusions should suddenly tail out as they enter belts of synclinal compression is surely more than a coincidence, and shows that the compression along the synclinal axes was already existent at the time of intrusion.

(4) Sufficient evidence that the major part of the transverse folding was posterior to the intrusions is furnished by the manner in which the intrusive masses are involved in the folds. Farther south the Silurian rocks are equally affected by similar folds.1

(ib) North-and-South Faults.

Although the north-and-south folds are so widely distributed, corresponding faults seem to be rare. The only faults of any importance are those east of Tyrau-mawr that partly replace the eastern limb of the Tyrau-mawr Syncline. One or two smaller examples were also observed on the cliff a little farther east.

A similar fault, but not with an eastward downthrow, partly replaces the eastern limb of the Peniarth Anticline, and is sufficiently powerful to cut out the whole of the Upper Acid

Group near Peniarth-uchaf.

(ii) The dip-faults need no special mention.

W. J. Pugh, Q. J. G. S. vol. lxxix (1923) p. 533.

(iii a & iii b) The Longitudinal or North-Easterly Folds and Faults.

These disturbances have only been noted in a few localities; they may, however, be more common than appears, and some may have escaped detection owing to their small size and limited effects. Both folds and faults may be considered together, and treated

according to locality.

A shallow syncline in the Talyllyn Mudstones is beautifully exposed on the western wall of Cwm Ammarch (Pl. XXXVI, fig. 2). The exposed part of the fold is about a mile wide, but the total wave-length must be rather greater, as the actual limits of the fold are not visible. For the same reason the total amplitude cannot be stated; but, as seen, it does not exceed 500 feet.

The southern spur of Mynydd Pencoed shows a wonderful adaptation of topography to geological structure. The steep eastern face is a scarp-slope descending to Cwm Anmarch, and it displays the folding as mentioned above. The upper grassy surface of the hill is seen to curve in perfect conformity with the bedding of the gently folded slates below. Moreover this gently curved grassy surface slopes south-westwards at about 15°, and this slope is defined by the pitch of the south-westerly-aligned Cwm-Ammarch Syncline into one of the larger north-and-south synclines.

Further, the southern limit of the spur is defined, as mentioned below, by normal faults that range south-westwards parallel with

the Cwm-Ammarch Syncline (fig. 2, p. 580).

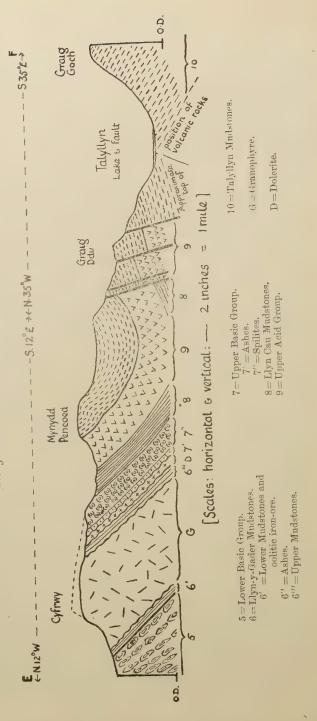
The north-western margin of the Cwm-Ammarch Syncline is modified by two minor folds, an anticline and the complementary syncline. These range north-east and south-west parallel with the main fold, but have a wave-length of only about 300 yards, as compared with a mile or more for the main fold. They are visible in the Talyllyn Mudstones, close above the volcanic rocks in the precipice of Craig Cwm Ammarch. They are visible again a mile and a quarter away to the south-west, on the side of Nant Pencoed.

The opposite or south-eastern margin of the Cwm-Ammarch Syncline is truncated by normal step-faults that range parallel with the fold, and throw down south-eastwards. Their effect is to truncate the southern spur of Mynydd Pencoed, and throw it down

about 400 feet to form the shoulder named Graig Ddu.

Graig Ddu shows an adaptation of topography to geology similar to that described above in the southern spur of Mynydd Pencoed. The beds are nearly horizontal. The south-eastern front is a precipitous scarp-slope determined by the highly inclined cleavage, the cleavage-dip being 70° south-eastwards. The gently sloping upper surface is again controlled by the bedding, and in conformity with the pitch this upper surface is inclined about 15° south-westwards. The formation of the cleavage-scarp is helped by normal faulting: this fault also ranges north-east, and throws down south-eastwards. The combined effect of these faults is to bring the same

Fig. 2.—Horizontal section illustrating the geological structure of the Gader Idris range and the Talyllyn Valley, along the line EF in the map (Pl. XXXVII).



beds that form the top of Mynydd Pencoed, down to the level of the Talyllyn Lake, and this is accomplished despite the beds being either horizontal, or inclined gently inwards towards the mountain (fig. 2, p. 580 & Pl. XXXVI, fig. 2). The significance of this in relation to the throw of the Talyllyn Fault is discussed later (p. 582).

Small north-east and south-west faults have been noted at other localities in widely different parts of the district. Several examples have been mapped in the Bird-Rock mass, throwing the volcanic rocks down to the north-west, and causing a small amount of repetition. Exactly similar faults are found on Craig y Llam. Faults of much the same type are seen near Penrhyn-gwyn: these also cause repetition: the fault-planes, visible in the gorges above

Penrhyn-gwyn, are practically vertical.

Another example occurs on Geu Graig, where it acts as a true strike-fault, throwing down south-eastwards. The fault-plane is vertical, and is seamed with quartz-veins. This fault helps to relieve a small north-easterly monoclinal fold that causes the beds to be vertical all along Geu Graig, instead of having the normal dip of 40°. If we view Geu Graig from the lower ground towards Cross Foxes, the dip of the Upper Acid Group is seen to diminish as the strata descend towards the valley of the Talyllyn Pass, and beds that are vertical on the summit-ridge dip at 60° or less on Mynydd Gwern-graig.

The sudden changes of strike on Mynydd Penrhiw in the Dysynni Valley are probably due to small folds with a north-easterly alignment which are hardly powerful enough to overcome

the steep southward pitch of the north-and-south folds.

(iii c) East-and-West Faults.

Two important east-and-west faults have been noted, forming the northern and southern boundaries of Mynydd y Gader. Both act in a general way as strike-faults. Their local and restricted occurrence is explained by the rather local distribution of the

east-and-west strike.

The Mynydd-y-Gader Fault was mapped by Mr. Lake & Prof. Reynolds,² and received brief mention in the Arthog paper (p. 312). It is a normal fault, throwing Arenig rocks against various members of the Upper Cambrian. Reasons have already been given (p. 546) for supposing that this fault masks an unconformity, and that its throw is not so great as might appear from the map. The fault does not make any feature, because the physiography is dominated by the dolerite-mass of Mynydd y Gader.

The Mynydd-y-Gader South Fault is also a normal fault, throwing southwards. It brings the pillow-lavas and ashes

¹ W. J. Pugh, 'Geology of the District around Corris & Aberllefenni' Q. J. G. S. vol. lxxix (1923) p. 536 & pl. xxvii.

² Q. J. G. S. vol. lxviii (1912) p. 346.

of the Lower Basic Group against the Arenig rhyolites, cutting out the whole of the *Bifidus* Beds. The throw decreases at both ends of Mynydd y Gader, letting in strips of the *Bifidus* Beds in the Aran Valley and at Penrhyn-gwyn respectively. The fault is accompanied by a good deal of shattering, which can be seen in the prominent fault-notch two-thirds of a mile east of Penrhyn-gwyn. From this notch the fault makes a boggy hollow, 20 yards or so wide, leading eastwards, with rhyolitic rocks on one side, and the agglomeratic Cefn-hir Ashes on the other.

Age of the east-and-west faults.—These two faults owe their existence to the resistance of the laccolitic mass of the Mynydd-y-Gader dolerite, with its associated massive rhyolitic rocks. The faults are probably of the same age as the north-easterly strike-faults: for, as the strike changes in the Aran Valley, the direction of the faults changes likewise.

(iv) North-East and South-West Shatter-Faults.

The Cader Idris range is bounded on the north and south by valleys excavated along the Gwernan Fault north of the range, and the Talyllyn Fault on the south. The Ceunant-Gwernan Fault was described in the Arthog paper (p. 312); accordingly, its

effects on the outcrops need not be further discussed.

The Talyllyn Fault has long been known to be the continuation of the Bala Fault. It makes the long straight Talyllyn Valley and the Talyllyn Pass, or Bwlch Llyn-bach (Pl. XXXVI, fig. 1). Within the pass the fault evidently pursues a slightly sinuous course. The fault itself is generally concealed beneath alluvium, and is nowhere actually exposed. The direction of hade is therefore unknown, but, by analogy with the Ceunant Fault, it probably acts as a normal fault with a northward downthrow.

The apparent vertical throw, as measured in a section across the Talyllyn Pass, is about 2000 feet (fig. 1, p. 544); but this semblance of a great vertical throw is probably due to a considerable lateral displacement, combined with a comparatively

small vertical displacement.

The structures of the slopes between Mynydd Pencoed and Talyllyn lake suggest that the volcanic rocks cannot be far below lake-level on the north side of the fault (fig. 2, p. 580, and Pl. XXXVI, fig. 1). But these volcanic rocks do not reappear at the lake on the south side of the fault, despite the southerly repetition. Therefore the amount of repetition must here be inconsiderable; or, in other words, the vertical displacement along the lake cannot be great. The great displacement of outcrops could be explained by lateral displacement, of the type described by Prof. O. T. Jones & Prof. W. J. Pugh 1 in the Llyfnant Fault, 8 miles south of Talyllyn.

With increased knowledge of the surrounding areas it should

Q. J. G. S. vol. lxxi (1915–16) p. 377.

become possible to identify some of the greater cross-folds with their former continuations across the belts of shatter-faulting. When this can be done, it will be a valuable clue to the direction and amount of movement along the faults, such as the Talyllyn Fault, in the same way that the movement along the Llyfmant Fault has been worked out. But, at present, details are lacking for a similar attack on the problems of the Talyllyn Fault and the other faults nearer Dolgelley.

There may, however, be an alternative explanation of the combination of a small vertical throw at Talyllyn lake and the large displacement of outcrops in the Talyllyn Pass. The Talyllyn Fault may be of the 'rotational' type, with a large real throw at one locality, and a small one at another, and the decrease in throw may be due to the westward approach of a more stable belt. On the north side of Cader Idris, the throw of all the southwesterly faults decreases westwards, until the faults ultimately disappear (Arthog paper, p. 313). There seems to be a north-and-south belt of country from Crogenen Lakes, through Craig y Llyn, to the Dysynni Valley near Llanfihangel Pennant, that remains almost, if not quite, unaffected by north-east-and-southwest faulting.

The faults that approach this belt from the east fail to penetrate it. But there is evidence that on the west side of this stable belt, north-east-and-south-west faults set in anew with

great suddenness.

One example is the Dysynni Fault, which is probably responsible for the long straight course of the Lower Dysynni Valley, and for the westward disappearance of the upper volcanic rocks (p. 567). The fault emerges from the alluvium at Garthfach, where it lets in a small lenticle of volcanic rocks. Its throw, where first seen, is great enough to cut out the whole of the Upper Acid Group, and the course of the fault is marked, either by a hollow, or by a strong quartz-vein. Yet, half a mile away to the east, on a continuation of the line, the outcrops on Craig Tyn-y-cornel are entirely unaffected, so that the powerful fault seems to die out suddenly as it approaches the 'stable belt'.

Thus important faults approach this stable belt from both sides, and yet fail to cross it. It is, therefore, not surprising that even where a fault, like the Talyllyn Fault, does succeed in crossing

the belt, its throw is reduced.

It is possible that the stable belt owes its existence to the fact that the movements on either side of it were mutually opposed, or, in other words, that it served as an axis about which rotation took place. For, while the Ceunant-Gwernan and Talyllyn Faults both throw northwards, the Dysynni Fault, on the opposite side of the belt, throws southwards. The evidence is not, however, conclusive, since east-and-west and north-easterly faults with southward downthrows do exist on the eastern side of the belt, as instanced by the Mynydd-y-Gader and Geu-Graig Faults.

V. COMPARISON WITH OTHER AREAS.

The correlation of the lower (Arthog and Lower Llanvirn) rocks of Cader Idris with those of other parts of North Wales, and of South Wales and Shropshire, has already been discussed (Arthog paper, p. 316). Accordingly, attention is here mainly confined to

a consideration of the higher beds.

Correlation with Arenig Mountain.—It is at once natural to compare the sequence on Cader Idris with the well-known sequence at Arenig, so fully worked out by Prof. W. G. Fearnsides.1 The lower and upper parts of the two sequences are then found respectively to be very similar. The general correspondence of the Arenig and Lower Llanvirn rocks of Cader Idris with those of Arenig Mountain has already been indicated (Arthog paper, p. 316). The higher beds also show many resemblances, but also certain important differences: the differences are especially marked in the middle portion of the sequence. The Lower Basic Group of Cader Idris evidently corresponds in horizon with the Lower Andesites of Arenig Mountain. In both areas the volcanic rocks rest on Bifidus Shales, and the volcanic episode opened with the emission of much fragmentary material, constituting the 'platy ashes and great agglomerate' of Arenig Mountain, and the exactly similar Cefn-hir Ashes of Cader Idris. Subsequently lavas were emitted in both districts. Lavas, however, evidently play a more important part in the volcanic group on Cader Idris than on Arenig. Also, the lavas of Cader Idris appear to have been rather more basic than at Arenig, so that they are represented by spilites showing pillow-structure, instead of by more intermediate or 'andesitic' rocks as on Arenig. Further, the great intrusions of silicified and porphyritic hyperstheneandesite of Arenig are not represented in the Lower Basic Group of Cader Idris. Thus the widespread vulcanicity at the top of the Lower Llanvirn Series shows a considerable variety in different districts: for instance, spilites on Cader Idris, andesites on Arenig Mountain and in Shropshire, rhyolites in Pembrokeshire; and more than one type may occur in a single district, as at Builth.

The Llyn-y-Gader and Llyn-Cau Mudstones of Cader Idris together may possibly correspond with the Daerfawr Shales of Arenig; but, if so, they differ in several respects. The strata at Cader Idris are much thicker, more argillaceous, and less pryoclastic than at Arenig. Moreover, at Arenig no representative of the oolitic ironstone has been found in situ, although erratics of ironstone were found along the Daerfawr-Shale outcrop. Further, there is nothing in the Daerfawr Shale of Arenig to correspond

with the Upper Basic Group of Cader Idris.

The Upper Acid Group of Cader Idris closely resembles, and apparently corresponds with the Upper Andesitic and Rhyolitic Group of Arenig Mountain.

¹ Q. J. G. S. vol. lxi (1905) p. 609.

Moreover, the Talyllyn Mudstones appear to correspond with the great mass of barren mudstones—the Nant-Hir Shales—that succeed the highest volcanic rocks of Arenig, although absolute proof of identity of age is lacking, owing to scarcity of fossils in both areas.¹ The beds at Arenig are rather darker than those above the Cader Idris volcanic rocks, and differ in containing the thin Derfel Limestone, which is not represented on Cader Idris. The correlation of the strata above the Talyllyn Mudstones with those in the Arenig-Bala district is described by Prof. Pugh.²

Tremadoc area.—The Cader Idris iron-ore is possibly on the same horizon as that at Tremadoc.³ The Llyn-y-Gader and Llyn-Cau Mudstones together correspond closely with the great mass of grey slates that succeeds the Tremadoc iron-ore. The flaggy adinoles interbanded with the Llyn-y-Gader Mudstones are exactly comparable with those in the lower part of the grey banded slates of the Tremadoc district; while the Upper Basic Group may correspond in a general way with one or more of the andesitic bands developed at a higher level in the grey slate-group of Tremadoc, although actual proof of this is wanting.

Comparing the three areas Cader Idris, Arenig, and Tremadoc, we find great differences in the thickness of the strata that apparently correspond to the Llyn-y-Gader and Llyn-Cau Slates. The strata are thick at Tremadoc and at Cader Idris, and include eruptive rocks in both areas; while their apparent equivalents on Arenig Mountain (the Daerfawr Shales) are thin, and do not contain any lavas. It will be noted that Tremadoc and Cader Idris lie respectively north-west and south-west of the Harlech Dome, and the variation seems to be such that the strata in question thicken westwards away from the Dome, on both its northern and southern sides. Although the evidence from these beds alone is admittedly scanty, it does suggest that the movements forming the Dome were already operative during Ordovician time.

Further evidence in support of this conclusion has already been adduced from the lateral variation of other groups of Ordovician strata, from the behaviour of the faults, and from the distribution of the intrusive rocks (Arthog paper, pp. 314 & 317).

Conway and Snowdonia.—The lowest beds of the Talyllyn Mudstones and the lower part of the Cadnant Shales of Conway 4 both yield, among other graptolites, Glyptograptus teretiusculus var. euglyphus. This is a matter of considerable interest, since both these mudstone groups rest without visible break immediately

¹ G. L. Elles, Q. J. G. S. vol. lxxviii (1922) p. 144.

² Q. J. G. S. vol. lxxix (1923) p. 539.

³ W. G. Fearnsides, Q. J. G. S. vol. lxvi (1910) p. 170.

⁴ G. L. Elles, Q. J. G. S. vol. lxv (1909) p. 180.

upon the highest volcanic rocks in their respective districts. It suggests that the main Snowdonian volcanic rocks occupy about the same horizon as the Upper Acid Group of Cader Idris. It appears therefore that Cole & Jennings were nearer the truth than they suspected, when they commented on the petrographical resemblance of the Craig-y-Llam rhyolites to those of Snowdonia.

It is, unfortunately, not yet possible to institute any correlation for the strata below the rhyolitic rocks in the two areas, owing to differences in sedimentation and to the scarcity of fossils in the lower beds of Snowdonia. Nothing corresponding to the Lower Basic Group of Cader Idris has been recorded in Carnaryonshire.

Central Wales: Builth and Llanwrtyd.—By combining the incomplete upward sequence at Builth with the incomplete downward sequence at Llanwrtyd, a succession is obtained that shows many points of similarity with Cader Idris. At Builth vesicular pillowy lavas overlie Bifidus Beds as on Cader Idris, although there are certain petrological differences in the rocks of the two areas.

The Builth volcanic rocks are followed by the Llandeilo Flags, which, of course, are not represented as such on Cader Idris. But it is significant that some of the graptolitic hard mudstone-bands which occur in the upper part of the Llandeilo Flags at Builth compare closely in lithology, and probably in their graptolites, with the mudstones associated with the oolitic ironstone of Cader Idris. Higher Ordovician strata are concealed by the Silurian unconformity at Builth, but appear a few miles away at Llanwrtyd.

The curious resemblance between the igneous rocks of Llanwrtyd (Breconshire) and the Upper Basic and Upper Acid Groups of Cader Idris has already been described by Prof. L. D. Stamp & Mr. S. W. Wooldridge.² The base of the Llanwrtyd rocks is not seen, and the igneous rocks themselves are greatly reduced in thickness as compared with Cader Idris; but there is no doubt that the volcanic rocks of the two areas correlate exactly. The presence of these rocks at Llanwrtyd gives an interesting clue to the southward extension of the higher volcanic rocks of Cader Idris, all trace of which disappears somewhere between Llanwrtyd on the one side and Carmarthenshire (and Pembrokeshire) on the other.

South Wales: Pembrokeshire.—Little comparison is possible between the Merioneth and the Pembrokeshire areas. The main similarity is that volcanic rocks are developed at the top of the Lower Llanvirn in both areas. The petrographic character of the lavas differs, however, in that the Cader Idris rocks are pillowy spilites (Lower Basic Group); whereas these of North

Q. J. G. S. vol. xlv (1889) p. 431.
 Ibid. vol. lxxix (1923) p. 32.

Pembrokeshire are mainly rhyolites, although spilites may occur

locally among the rhyolites.1

Above the Llanvirnian volcanic rocks the detailed sequences are quite different, since no volcanic rocks occur above the *Didymograptus-murchisoni* Zone in Pembrokeshire, whereas in Merioneth vulcanicity continued at intervals throughout the Llandeilo epoch up to the time of the *Arctus* Beds.

The Lake District.—A curious parallelism exists between the sequence of events at Cader Idris and in the Lake District, as indicated in the following synopsis:—

Cader Idris.

Upper Acid Group.
Llyn-Cau Mudstones.
Upper Basic Group.
Llyn-y-Gader Mudstones and
Ashes.
Lower Basic Group.
Cefn-hir Ashes.
Lower Llanvirn Slates and
Arenig Beds (with Lower
Acid Group).

Lake District.²

Sorrowdale Rhyolites.
Upper Borrowdale Andesites.
Harrath Tuffs.
Wrengill Andesites.
Middle Tuffs.
Lower Andesites.
Mottled Tuffs.

Skiddaw Slates.

There is little doubt that the main vulcanicity started simultaneously in both areas towards the end of Lower Llanvirn time. But it would be premature to suggest exact correlation for the higher groups in the two areas, for there are considerable petrographic differences between the respective lavas. Also, vulcanicity appears to have been more continuous in the Lake District, so that the various volcanic rocks are not separated by slates and mudstones as on Cader Idris. It has, therefore, not proved possible to fix an exact age for the higher members of the Borrowdale Volcanic Series. The difficulty of fixing an upper time-limit to the volcanic episode is increased in the Lake District by reason of the gap in the sequence due to the unconformity at the base of the Coniston Limestone Series.

VI. SUMMARY AND CONCLUSION.

Cader Idris shows a sequence of Ordovician rocks from Arenig to early Bala. The district adjoining continues this sequence up to, and into, the Silurian Period.

The Arenig rocks rest with probable unconformity upon various divisions of the Upper Cambrian. The unconformity increases in importance eastwards, but is partly masked by faulting.

The Ordovician rocks of Cader Idris contain four 3 different groups of volcanic rocks, separated from one another by considerable

¹ Observations of the Author, not yet published.

² J. F. N. Green, 'Vulcanicity of the Lake District' Proc. Geol. Assoc. vol. xxx (1919) p. 168.

³ Five, if the Dolgelley outlier of the Rhobell Fawr volcanic rocks is included.

thicknesses of slate, showing that each group of volcanic rocks represents a separate and distinct episode.

Each volcanic group contains intercalated bands of slate and of

bedded ash, proving a submarine origin.

Excluding the Dolgellev outlier of the Rhobell Fawr volcanic rocks, the lowest volcanic rocks of Cader Idris are a group of rhyolitic rocks of Arenig age. These are underlain by the local Arenig Basement Series, and overlain by Bifidus (Lower Llanvirn) Beds. The rhyolitic rocks themselves contain, locally, intercalated bands with extensiform and some tuning-fork graptolites. The age of the rhyolitic rocks is best determined in the Arthog area on the west. Eastwards, nearer Cader Idris, their relations to the beds above are obscured by an overlap of higher strata and by strike-faulting.

The Lower Llanvirn (Bifidus) Beds are represented by slates and ashy grits, and yield the zonal graptolites. The sequence among these beds is likewise best determined in the west, because an overlap within the group increases in importance castwards, and

faulting also increases eastwards.

A group of agglomeratic and fine-grained 'andesitic' ashes—the Cefn-hir Ashes—succeeds the *Bifidus* Slates. The ashes contain in their upper part a band of shales that yield *Didymo*-

graptus bifidus.

The agglomerates are followed by the second of the volcanic groups—the Lower Basic Group—a thick series of pillow-lavas with some intercalated shale- and ash bands and associated basic intrusions. These seem to replace the Upper Llanvirn and a great part of the Landeilo Series.

The basic lavas are overlain by an oolitic iron-ore that represents

a definite stratigraphical horizon.

The iron-ore forms the base of a mudstone group—the Llyn-y-Gader Group—which includes some agglomeratic and adinole-like ashes intercalated in the mudstones.

The mudstones are followed by the third volcanic group—the Upper Basic Group—pillow-lavas passing laterally into agglomeratic ashes, and overlain by 500 feet of almost unfossiliferous mudstones—the Llyn-Cau Mudstones.

The fourth volcanic group—the Upper Acid Group—consists of 500 to 1500 feet of rhyolitic and acid 'andesitic' lavas and ashes. Some of the rhyolites are nodular. The highest volcanic rocks

are well-bedded and highly silicified ashes.

The volcanic rocks are overlain by a very thick series of mudstones and slates, the Talyllyn Mudstones, of Bala age, with no trace of any further volcanic episodes. The lowest strata of this series correspond to the *Arctus* Beds of South Wales and to the lower part of the Cadnant Shales of Conway, and are to be assigned to a low horizon in the Bala. They succeed the volcanic rocks abruptly, but probably without any stratigraphical break.

The strata between the oolitic iron-ore and the Talyllyn Mud-

stones have vielded only Glyptograptus teretiusculus.

The volcanic rocks of Cader Idris thus have a much greater time-range than had been proved hitherto, and range in age from

Arenig, Lower Llanvirn, Llandeilo, to (?) early Bala.

Intrusive rocks are represented by numerous dolerite-sills, both small and big, and by two great sills of granophyre, which are later than the dolerites. No basic intrusions occur above the highest basic extrusive rocks, and no acid intrusions above the highest acid extrusive rocks.

The main structures have a Caledonian trend, north-east and south-west, but there is also a minor system of north-and-south folds that often have a marked effect on outcrops. The minor folding was operative in pre-Ordovician time (as shown by the relation of the Ordovician to the Cambrian), also during Ordovician time: for the folds seem to have influenced sedimentation, and they certainly controlled the emission and extension of the major acid intrusions, which originate in anticlines and terminate in synclines.

The minor folding was, however, not completed until Silurian or

post-Silurian time.

In conclusion, it may be pointed out that the Cader Idris sequence is one of the most consistently volcanic sequences so far described from North Wales, and the volcanic rocks can no longer be considered, in accordance with Ramsay, as entirely of Arenig age, and therefore lower than the volcanic rocks of Snowdonia. It appears indeed that, whereas the volcanic rocks in the two districts end at the same horizon, they begin earlier on Cader Idris than in Snowdonia, so far as one may judge from published accounts.

The main mass of the Cader Idris eruptions took place in Glenkiln time, so that the main volcanic horizons seem to be more nearly in line with those of the Lake District than would appear

from the earlier writings.

Exactly where the boundary between the Landeilo and the Bala should be drawn on Cader Idris is not yet clear. The most natural place would appear to be at the top of the Upper Acid Group, but it depends on the interpretation of certain South Wales sections as to whether the boundary should be drawn somewhere in the mass of mudstones that intervene between the dark slates with the oolitic iron-ore below, and the Upper Acid Group above.

One other point that may be noted is that some modification is required of the statement made by Cole & Jennings, and also by Geikie, that there is an upward succession from basic to acid volcanic rocks on Cader Idris. This statement certainly holds good if only the upper half of the sequence is considered; but when the complete Ordovician sequence is taken into account, the volcanic rocks are found to have an acid composition in the earliest and latest eruptions, and a basic composition in the eruptions of the middle periods. The four volcanic groups are, however, separated one from the other by thicknesses of sedimentary rocks so considerable, that they cannot be considered as belonging to a single volcanic episode. It is significant that all the volcanic groups thin to the west.

I wish to acknowledge my indebtedness to Mr. N. G. Blackwell, B.Sc., for frequent companionship in the field, and for the photographs that illustrate this paper, and to Mr. John Pringle, F.G.S., for his identifications of some of the graptolites.

I have also to acknowledge grants from the Royal Society which have helped to defray certain of the expenses of the investigation.

VII. ADDENDUM: TRAVERSES OF THE CADER IDRIS SEQUENCE.

(1) The best traverse of the Cader Idris sequence closely follows the line of the direct path from Llyn Gwernan to the summit of Cader Idris, and then

of the path from the summit to Talyllyn and Abergynolwyn.

Llyn Gwernan, where the path leaves the road, is $2\frac{1}{2}$ miles from Dolgelley (Arthog paper, map, pl. xx). The path skirts the flank of Mynydd y Gader, and runs for some distance almost parallel to the junction of the Lower Acid Group with the Bifidus Beds; but the geology is not very clear, owing to small transverse faults, and to radial dissection by small streams flowing more or less in the direction of pitch. The rocks seen mostly belong to the ashy upper portion of the rhyolitic group. At a point half a mile from Llyn Gwernan, by some sheepfolds where two paths join, a small vertical face shows banded and cleaved rhyolites. (In order to see the rhyolites to the best advantage, it is necessary to make a detour and ascend Mynydd y Gader, which, if time permits, is best made the object of a separate excursion.) The path proceeds mostly over drift until a dolerite in the Cefn-hir Ashes is reached, but little is seen of either the Bifidus Slates or the Cefn-hir Ashes. (An alternative traverse to this point is the path that ascends from the Dolgelley road past Penrhyn-gwyn Farm, passing over the intrusive rocks of Penrhyn-gwyn, the Bifidus Shales, and the Cefn-hir Ashes, all well exposed on the path or in the Penrhyn-gwyn stream.) Above the doleritesill the upper portion of the Cefn-hir Ashes is exposed, and the associated shales are visible in the stream.

The path then proceeds over drift, with occasional small exposures of pillow-lavas, to Llyn y Gafr. Beyond Llyn y Gafr the path ascends more steeply, and, by diverging a little either to the east or to the west of the path, and then making the ascent, the characteristic lavas and ashes of the Lower Basic Group may be well seen. The volcanic rocks are succeeded, near the terminal moraine of Llyn y Gader, by the colitic iron-ore with its associated slates. These are not exposed on the path, owing to the moraine; but they are well seen a little to the east. The sequence on the cliffs above Llyn y Gader is quite clear, and the section is one of the most striking in North Wales (Pls. XXXIV & XXXV). The usual way to the summit is by the Foxes' Path; there is also a wide choice of easy or difficult routes up the cliffs. A fairly easy ascent is through the small fault-gully indicated in

the photograph (Pl. XXXIV).

At the summit the pillow-lavas of the Upper Basic Group are well displayed. Thence a path leads down the pillow-lava outcrop to the head of Bwlch Cau, on the outcrop of the Llyn-Cau Mudstones, with good views into one of the wildest cwms in Wales. (From Bwlch Cau a path leads down by way of the slate-scree and the south side of Llyn Cau, and finally down the west side of a fine hanging-valley to Minffordd, near the head of Talyllyn lake. The effects of river-capture along the Talyllyn Fault-line are diagrammatically displayed: the stream from Llyn Cau evidently represents the former head-waters of the Corris River.)

From the head of Bwlch Cau the path to Abergynolwyn ascends the flanks of Craig Cau to the high col between Craig Cau and Mynydd Pencoed, passing over the outcrop of the Upper Acid Group. The lowest rocks seen on this ascent are the ashy slates that constitute a transitional stage from the Llyn-Cau Mudstones to the overlying volcanic rocks. These ashy slates

form a small crag and a small ridge between two lateral streams. They are followed by a small thickness of less ashy slates, which form the weak zone occupied by the southern of the two streams. The slates are followed by the nodular fluxion-brecciated rhyolite mentioned on p. 565. The rhyolite is well exposed on the path. By diverging a little west of the path at this point and following round the head of the precipices above Llyn Cau, some impressive 'chimneys' are seen, and almost every bed in the volcanic group may be examined. On the col leading to Mynydd Pencoed the flaggy ashes at the top of the volcanic group are seen dipping down into Cwm Ammarch. The path skirts the western side of Cwm Ammarch, with good views of the gentle folding of the Talyllyn Mudstones in the Cwm-Ammarch Syncline (p. 579 & Pl. XXXVI, fig. 2). The path then passes over Mynydd Pencoed and down its southern shoulder, crossing the shallow syncline, ultimately descending to Graig Ddu (p. 579) and to the Talyllyn and Towyn road.

- (2) Other good traverses may be made up the Aran Valley. A rough road leads from Dolgelley up the east side of the river through the beautiful Aran Glen, excavated in Ffestiniog Beds with doleritic intrusions. Farther up there are, close to the road, small exposures of most of the various beds in the Arenig and Lower Llanvirn Series, but the exposures are not well connected. Beyond the farm at Bwlch Coch a path leads over the outcrop of the Lower Basic Group to a trial in the oolitic iron-ore immediately south of the watershed. (This path then descends to the head of the Talyllyn Pass, but does not furnish a good traverse for actual examination of the rocks) From the trial-level a path leads westwards for a quarter of a mile, after which a way may be made up Geu Graig. The eastern corrie below Geu Graig, carved in the Llyn-Cau Mudstones, with northern and southern walls of pillow-lavas and rhyolitic rocks respectively, is an impressive sight. From Geu Graig a way may be made down the cliffs of the Upper Acid Group, and thence down to the Talyllyn Pass.
- (3) Another road from Dolgelley leads up the west side of the Aran Valley to the junction of the Aran and Ceunant Valleys, where the Ceunant Fault is well-exposed in the eastern bank of the Aran. Then a way may be made over the eastern flank of Mynydd y Gader, and down to the upper part of the Aran Valley, thence across the drift-filled valley to Llyn Aran, and up one of the screes made by the Upper Basic Group, to the flat-topped ridge at 2000 feet. A rough and steep descent leads across the Upper Acid Group to the Talyllyn Valley. This route is not recommended in misty weather.
- (4) The stratigraphical relations of all the groups, from the Tremadoc to the Bifidus Beds and Cefn-hir Ashes, are much better seen by making a traverse across Bryn Brith, or by ascending the valley that leads from Arthog to the Crogenen Lakes (Arthog paper, p. 259 & map, pl. xx). They are also well seen by traversing the hills on the west side of the Arthog Valley. The ordinary path from Arthog to Tyrau-mawr and Cader Idris is mostly on drift or along grassy slopes, and is not especially interesting.

EXPLANATION OF PLATES XXXIII-XXXVII.

PLATE XXXIII.

Cader Idris, seen from the west side of Gelli-lwyd. The main escarpment is due to the granophyre sill forming Mynydd Moel (M), Foxes' Path (F), & Cyfrwy (C). On Pen y Gader (P), higher strata appear (see Pl. XXXIV). 5-5 marks the outcrop of the Lower Basic Group; 4-4, that of the Cefn-hir Ashes, with dolerites; 3-3, that of the Bifidus Slates—the right-hand 3, Penrhyn-gwyn Quarry; D, the Penrhyngwyn dolerite; and G-G, the Penrhyn-gwyn granophyre outcrop. In the foreground is the drift-covered floor of the Gwernan Fault-valley.

Q. J. G. S. No. 324.

PLATE XXXIV.

Cader Idris, seen from Llyn y Gader. G=granophyre, with dark Llyn-y-Gader Mudstones above; D=dolerite, with a thin slate-band above; 7'=basal ashes of the Upper Basic Group; f-f=fault-gully. granophyre-scree on the left is the Foxes' Path.

The dips seen are all apparent dips, and the synclinal appearance is mainly due to corrie-formation; the true dip is 40° southwards,

that is, away from the observer.

PLATE XXXV.

Cader Idris, seen from Cyfrwy. Beds as in Pl. XXXIV. G-G=columnar granophyre; 6-6=Llyn-y-Gader Mudstones, with intercalated pale ash-bands; D=dolerite; 7'=ashes; and 7"=pillow-lavas of the Upper

The highest point shows the cairn on Pen y Gader. The Foxes' Path descends to Llyn y Gader. The granophyre escarpment continues to Mynydd Moel. The dips are apparent dips. The

vertical distance from the summit to lake-level is 1100 feet.

PLATE XXXVI.

Fig. 1. Talyllyn lake, looking up the valley. The Upper Acid Group is repeated by the Talyllyn Fault, and forms a steep dip-slope at 9, and a scarp-slope on Craig y Llam (9_1) , with Bwlch Llyn-bach (F) on the fault-line, in between. G marks Mynydd Moel, composed of granophyre intrusive into the Upper Acid Group.

2. Cwm Ammarch, from above Talyllyn lake. In the foreground is part of the lake with deltaic deposits. 9 marks the highest volcanic rocks of Craig Cwm Ammarch dipping at 40° towards the observer, and under the Talyllyn Mudstones in the Cwm-Ammarch Syncline (10). The nearer crag to the left of the picture is Graig Ddu. The stream

has formed a delta of arable ground.

PLATE XXXVII.

Geological map of the Cader Idris district, on the scale of 2 inches to the mile, or 1:31,680.

DISCUSSION.

Prof. W. G. FEARNSIDES congratulated the Author on his completion of the mapping of the Cader country, and on his presentation of the stratigraphical results. It is clear that the Arenig-Llandeilo volcanic rocks of Cader, even without the great granophyric and doleritic intrusions, must show a thicker, fuller, and petrographically more variable, succession of eruptions than in any other part of Wales. The proving of the lateral continuity across the Cader tract of the Lower Rhyolites and Lower and Upper Spilites and associated slate-bands, all intercalated within the apparently equivalent and complete rock-succession of Arenig Mountain (but not there represented), is important, and a valuable caveat against hasty generalizations concerning the age and succession of Ordovician volcanic rocks in other districts.

The finding of the Glyptograptus-teretiusculus fauna in mudstones closely associated with oolitic iron-ore suggests comparison



CADER IDRIS, SEEN FROM THE WEST SIDE OF GELLI-LWYD.





to.







Quart. Journ. Geol. Soc. Vol. LXXXI, Pl. XXXVI.

Fig. 1.—Talyllyn Lake, looking up the valley.



N. G. B. photo.

 $\begin{tabular}{l} [9 = & teep & dip-slope & of the Upper Acid Group; & G = Mynydd Moel; \\ & F = & Bwleh & Llyn-bach & Pass.] \end{tabular}$

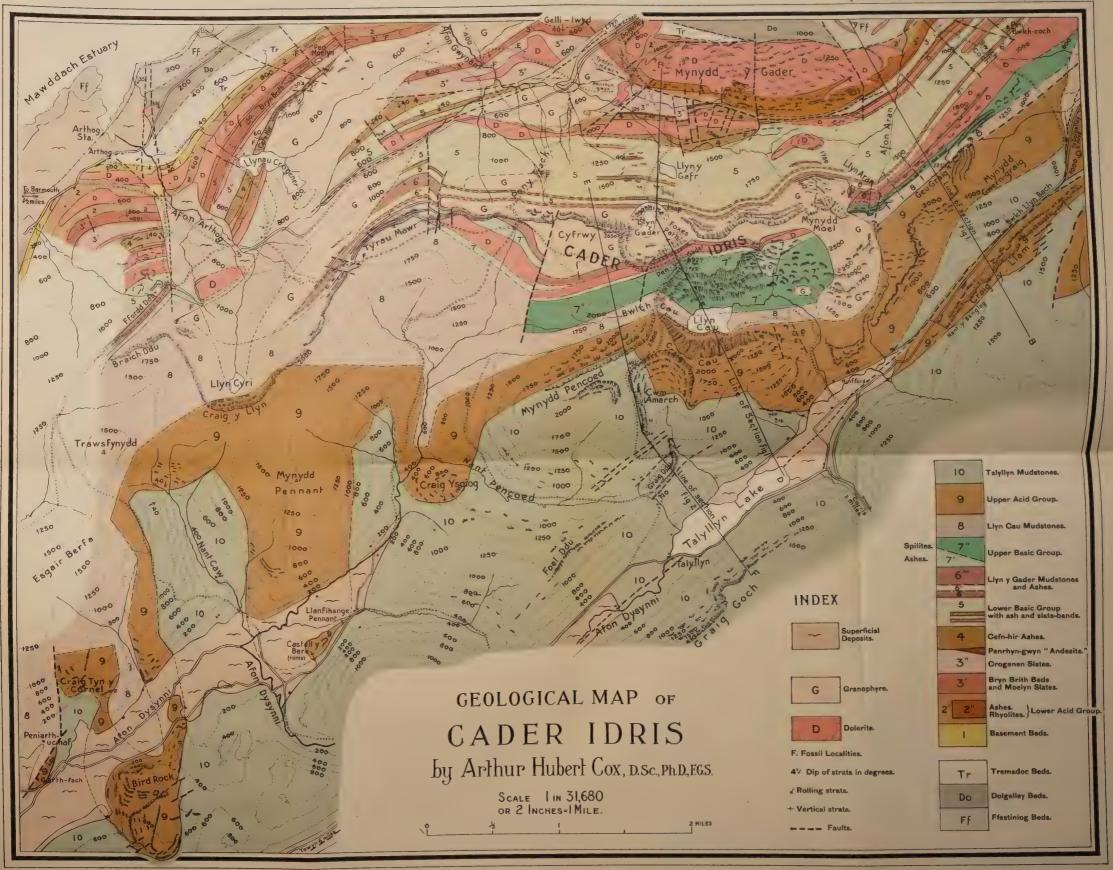
 ${\bf Fig.}~2. -Cwm~Ammarch, from~above~Talyllyn~Lake.$



N. G. B. photo.

[9=highest volcanic rocks of Craig Cwm Ammarch; 10=Cwm Ammarch Syncline.]







with the pisolitic iron-ore deposits at Penmorfa and Tremadoc; but in that district no spilitic lavas have yet been discovered, either below or above the ore, and the needle-slates which adjoin the several ore-lenticles contain graptolites belonging to three or more distinct assemblages within the Llandeilo Series. At Tremadoc, in fact, the alignment of the old iron-workings follows one major and several minor thrust-planes, and the neighbouring well-characterized adinole-formation seems to be limited to the metamorphic aureoles of the later massive intrusions of gabbroid dolerite.

With regard to the apparently anomalous and variable behaviour of the granophyric and slaty rocks in the determination of topography, the speaker suggested that in Preglacial times most of the igneous rocks of North Wales, being comparatively susceptible to chemical attack, were at their outcrop much more profoundly weathered than the slates. Under glacial conditions unweathered slate was slowly abraded, but the decomposed igneous rock was rapidly and completely worn away. When the weathered material had disappeared the rate of denudation slackened considerably, and on the high ground erosion was mainly effective through the plucking-out of joint-blocks piece by piece, so that the rate of removal of material was determined rather by the disposition, frequency, and continuity of the joints, than by the intrinsic hardness of the rocks themselves.

Dr. A. K. Wells complimented the Author on the completion of the mapping of this highly important range. He referred to the marked and comparatively sudden changes in thickness of the various divisions of the Ordovician succession, and asked for information concerning the eastward thinning of the Bifidus Beds and the Lower Basic Group. He had no hesitation in correlating the volcanic rocks east of Rhobell with the Upper Basic and Upper Acid Groups of Cader Idris. He commented upon the probability of these groups lying entirely within the single zone of Nemagraptus gracilis, as the fauna of this zone occurs below the volcanic rocks in the Rhobell area and above them at Arenig Mountain.

The PRESIDENT (Dr. J. W. Evans) asked, with reference to Prof. Fearnsides's remarks on the greater general erosion by 'plucking' of the granophyre than of the slates, whether the former was more extensively jointed than the latter. In Scandinavia the occurrence of jointing certainly appears to have been of primary

importance in facilitating 'plucking'.

The AUTHOR, in reply, stated that he was fortunate in having the results of Prof. Fearnsides's researches on Arenig as a general guide to what might be expected on Cader Idris. Parts of the two sequences certainly presented considerable differences. He agreed that detailed examination of other areas would probably yield some unexpected results. The term 'Basement-Beds' had been used for a group of arenaceous strata that formed the local base of the Ordovician sedimentary rocks. This local base was

probably some distance up in the Arenig zonal succession; but it was desired to avoid, so far as possible, the introduction of new stratigraphical place-names. He was quite satisfied that the oolitic iron-ore occurred at a constant stratigraphical horizon, and represented a definite sedimentary stratum. He was well aware of oolitic iron-ores at other horizons: as an example, he instanced the discovery by Dr. Wells of an oolitic band above the Lower Acid Group on Moel Offrwm, north of Dolgelley. It certainly appeared that there was little zonal difference between the fossils below and those above the upper volcanic rocks, and he considered that the 3000 to 4000 feet of mudstones and volcanic rocks, from the Llyn-y-Gader Group upwards, would all be represented in Pembrokeshire by a relatively small thickness of strata. He had devoted a good deal of attention to the petrology, but concluded that it was rather a matter for a separate paper.

18. The Liassic Rocks of the Radstock District (Somerset). By John William Tutcher and Arthur Elijah Trueman, D.Sc., F.G.S. (Read May 20th, 1925.)

[PLATES XXXVIII-XLI.]

CONTENTS.

		Page
I.	Introduction	595
II.	The Zonal Succession	597
	Details of Sections	600
	(A) Lower Lias.	
	(B) Upper Lias.	
IV.	General Discussion of the Structure and Relations of the	
	Lias of the Radstock District	625
V.	Note on the Origin of Nodular Limestones	634
	Faunal Notes	635
	Bibliography of the Radstock Lias	660

I. Introduction.

The Liassic rocks described in this paper are those found within a radius of about 4 miles of Radstock. The area dealt with is a low plateau, about 400 feet high, capped by Oolites and dissected by a number of rather narrow valleys. The Lias quarries are generally situated just below the plateau-level; the valleys are usually in deep red Keuper Marl, but in some of them the horizontal Mesozoic rocks are seen resting on gently folded Coal Measures, which have long been worked in the neighbourhood.

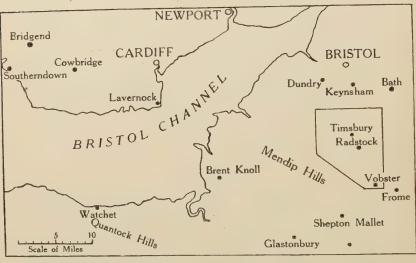
The Liassic rocks of this area have attracted considerable attention, because they are unusually thin, and in the lower part, exceptionally fossiliferous. The Lower Lias (Hettangian, Sinemurian, and Lower Charmouthian) is exposed in a great number of small quarries in the neighbourhood, and as each of these shows the entire succession from White Lias to Charmouthian, considerable detail concerning the sequence is available.

The peculiarities of the Liassic rocks of the district result from the fact that the area is situated immediately north of the Mendips; it is well known that there was repeated movement along this axis, intermittently from post-Carboniferous times until well into the Mesozoic. The consequences of these movements are seen at Radstock:

(i) in the condensed development of certain Liassic zones; the whole of the Lias thins as it is traced from Gloucestershire southwards to the Mendips, and from Dorset northwards.

(ii) in the numerous non-sequences which have resulted mainly from penecontemporaneous erosion. The non-sequences are in several cases marked by beds of phosphatized nodules with 'derived' fossils; but at other horizons important non-sequences are indicated by palæontological evidence, although no stratigraphical evidence of a break in sequence is apparent. It is remarkable, however, that notwithstanding the thinness of the Radstock Lias, an unusual number of ammonite faunas are richly represented.

Fig. 1.—Sketch-map of Somerset and the Bristol Channel, showing the relative positions of the localities to which reference is made.



The general succession in the Radstock area may conveniently be summarized as below:—

	Thickness in	ı feet.
UPPER LIAS,	Sands, marl, and ironshot limestoneunknown, probably not represented.	0-9
LOWER LIAS,	Striatum and Capricornum Clays	$\frac{120}{1\frac{1}{4}}$
	Valdani Limestone about Jamesoni Limestone yellow ironshot limestone	6-10
	Armatum Bed, with derived Echiocerates	$0-1\frac{1}{2}$ $0-1\frac{1}{2}$
	Raricostatum Clay Obtusum Nodules	$\frac{1}{4}$ $-2\frac{1}{2}$
	Turneri Clay Spiriferina Bed	0-5
	Bucklandi Bed, with Euagassiceras spp	0-1
	Nodular limestones and shales, Angulata and Planorbis Zones	2-30
	WHITE LIAS, with the Sun-Bed at the top	20

The sequence may, therefore, be compared with areas farther north, as follows:—

		Keynsham	
	Radstock.	and Bath.	Gloucester.
Upper Lias	9 feet.	? 30 feet.	230 feet.
Middle Lias	Absent.	Probably absent.	150 ,,
Lower Lias	190 feet.	280 feet.	? 350 ,,

In the present paper we have endeavoured to trace in some detail the nature and effects of the intra-Liassic movements in the area; we believe that such movements may be more readily demonstrated in this region than in any that has yet been described in detail. The detailed account of the stratigraphy has been made as brief as possible, while including the facts necessary to an interpretation of the structure. The palæontological section is necessarily lengthy; for, although it is impossible in this paper to give an account of all the faunas, it appears to be desirable to indicate as precisely as possible the fossils which are of zonal importance in the area.

A complete list of references to works dealing with the Lias of the Radstock district is given on pp. 660-61, and it does not appear to us necessary to recount in detail the history of investigation in the area. Apart from early references to the Radstock Lias, little attention was paid to it until after 1860. In the early maps of the area the Jamesoni Limestone was mapped as Inferior Oolite. From 1867 onwards a series of valuable studies on the Lias of the area was made by Tate, Moore, Tawney, and H. B. Woodward. Some of these workers made serious errors in identifying the ammonites, and their zonal work was necessarily too inaccurate to admit of a general study of the relations of the deposits.

More recently, some reference has been made to the Lias by Mr. L. Richardson, chiefly in the course of his researches on the Rhætic and the Inferior Oolite, while a summary of the ammonite sequence by Mr. S. S. Buckman and one of us (J. W. T.) was published in 1917. From time to time Mr. Buckman has also figured specimens from Radstock in his 'Type Ammonites', and other fossils from the area have been described in other

publications.

We desire to express our deep indebtedness to Mr. S. S. Buckman, not only for his kind and ready assistance in the study of the ammonites and brachiopods, but also for his constant encouragement and for the inspiration which his work has afforded to us; it will, of course, be obvious that this paper would not be possible, but for his monumental labours in Jurassic stratigraphy. From quarry-owners and workmen every kindness has been received, more especially from Mr. G. Denning, of Rockhill, and Mr. Job Hodder, of Timsbury. One of us (A. E. T.) has also to acknowledge the receipt of a grant from the Royal Society, which helped to defray part of the expenses during the initial stages of his work in the area.

II. THE ZONAL SUCCESSION.

In the accompanying table of zones (facing p. 598) we have summarized recent views of the ammonite succession in the Lower Lias (Hettangian to Charmouthian). This table is largely based on the masterly work of Mr. S. S. Buckman on Jurassic chronology,1 but has been modified in respect of more recent work by Dr. W. D. Lang, Dr. L. F. Spath, and others. An attempt is made in the table to correlate the zonal terms of the older workers with these smaller stratigraphical units; but a complete correlation is impossible, since the smaller units represent rather an amplification than a subdivision of the original zones.

It is not our intention to discuss this table, or the records on which it has been drawn up; our work at Radstock, from the attenuated character of the deposits and the obviously derived nature of many of the ammonites, has naturally made it impossible to add much detail to the succession. The divisions are named here, however, in order to show which of the hemeræ are represented, either by thin deposits or by derived specimens. The deposits at Radstock are sufficiently complete to confirm in a general way the reading of the succession within the jamesoni beds given by Dr. Spath, and his sequence is adopted here. Further, our work at Radstock has shown that the horizon of certain thin oxycones related to Radstockiceras is much higher than Mr. Buckman suggested.4

While strongly convinced of the value and reliability of this detailed sequence, it appears to us that it may be more convenient in the description of this particular area, to use the zonal terms in their broad and better known sense. This will allow sufficient accuracy in the general description, and will probably make the account more readily intelligible; the smaller divisions are inserted where the information is available. One of us has suggested that these smaller units should not be termed zones, owing to the confusion which such a practice may cause 5; but, as the term that he suggested has not received much support, it is not used in this joint paper.

We follow the practice that each of us has previously adopted, of grouping the White Lias with the Lias, rather than with the Rhætic. This is desirable on palæontological grounds, and in Somerset on lithological grounds also. As the White Lias is clearly transitional from Rhætic to Lias, however, the fixing of

any boundary must be, to a great extent, arbitrary.

¹ S. S. Buckman, 1917; also 'Jurassic Chronology—I. Lias: Supplement 1,

etc.' Q. J. G. S. vol. lxxvi (1920) p. 66.

² W. D. Lang, 'Shales-with-"Beef'': Part i' Q. J. G. S. vol. lxxix (1923) p. 47; and 'The Blue Lias of the Devon & Dorset Coasts' Proc. Geol. Assoc. vol. xxxv (1924) p. 169.

³ L. F. Spath, 'On the Liassic Succession of Pabay (Inner Hebrides)' Geol. Mag. vol. lix (1922) p. 548; and 'Correlation of the *Ibex & Jamesoni* Zones of the Lower Lias,' *ibid.* vol. lx (1923) p. 6.

⁴ Evidence recently obtained in Dorset indicates that the horizon of Gleviceras is higher than is shown: see L. F. Spath, 'Notes on Yorkshire Ammonites, III: on the Armatus Zone', The Naturalist, 1925, p. 167.

⁵ A. E. Trueman, 'Some Theoretical Aspects of Correlation' Proc. Geol.

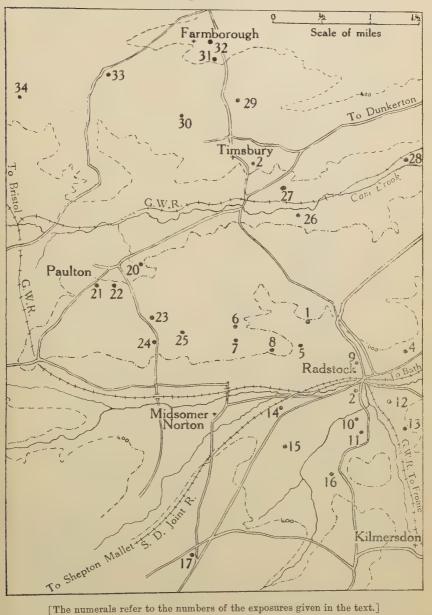
Assoc. vol. xxxiv (1923) p. 193.

TABLE OF ZONAL TERMS IN THE LOWER LIAS.

Oppel's Zones.	Geological Survey L nes.	S. S. Buckman, with additions and emendations by J. W. Tutcher, L. F. Spath, and A. E. Trueman.		Horizons known in the Radstock District.	Little Control of the at Records	W · · · · · · · · · · · · · · · · · · ·	
davæi.	capricornus.	Oistoceras. dadalicasta. drivai. breviluhatum. latæosta. Beauiceras. chel tiense. sparsicasta.	HWICCIAN.	1 brevilohatum. lateconta. Beanicevas. chelliense.	ths		
det 	, jamesoni.	rentamum. uctem. mangenesti. ibor. misseaunm. pettus. jameoni. oksidat. brevispina [with Radstockiceras]. pergorinum. taylori [Ehricodoceras].	Wisservice	brerispina. polymorphis. Phricodoceras.	Falton kanestee Jamestee Lanesteet	the Belemnite-	
armatus. raricustatus.	ara dus raricostatus.	leckenhyi. lorioli. nardonnellii. raricontaloiles. tuhollum. rhodanicum (aneum). zieteni. armatum. anyuiforme. suhplamianta. lispinig-rum. deaniodulum.	- IS AASATAN	leckenbyi, lorioli. aplanetum [derived], macdonnellii [derived], raricontatoides [derived], zieteni. subplanicosta.	Armatum Tion and Responsesses		
	oxynotus.	lymense. Glevicevas. robustum. polyophyllum. oxynotum. biferum. simpsoni. gagateum.	DEFEASE	Gleviceras [derived].	Clay		
obtusus.	obtusus.	lacunata. subpolita. denotatus. stellare. planicostu. sagittarium. obtasum. turueri.	MPRCLUS.	st llare planvosta, Musum tuvuen.	Ohtusica Nod des and Turners Clay.	Franches, M., co.	
Pentaerinus tuborculatus.	semicostatus.	birchi. hurdmanni. sulcifer. alcinoe. sunceaum. scipionianum. gunendense. ver rape v meridionalis. bucklandi. rotator.	Lymes.	hardmann, salemor, sanesaann, sepona rimm kervel, guan beass do, 'excengel our do, an el fondalis do, A Coroacersts do,	Spreeferma Bed and Buckbandt Bed.	Spreedo con Para	
angulatus.	angulatus.	conybearei. tagalata vaatemeeet. lussieus. Psaloophollites. megastoma.	HETTAGICS.	lusieus.	Anguiata Zone. (Limestones and shahes)	-	
planorhis.	planarhis.	jahustani. planarbis. liasswa. tatei.		plastent. plasorlis. liassica.	Planorhis Zone. (Limestones and shales.	Com tint.	
		langportensis.		langportensis.	White Lins.	Sun-lied White Las.	



Fig. 2.—Sketch-map of the Radstock district, showing the positions of the exposures described.



[The numerals refer to the numbers of the exposures given in the text.]

III. DETAILS OF SECTIONS.

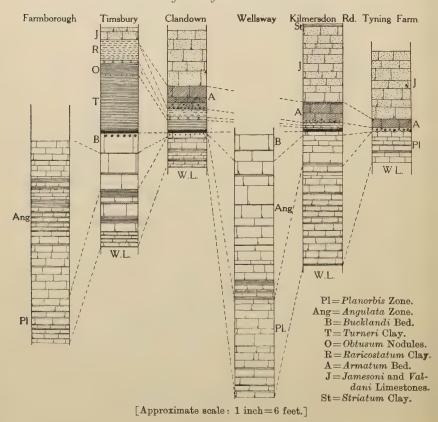
As most of the sections show the sequence from the White Lias to the *Striatum* Clay, and, as higher zones have been seen in only a few places, it will be convenient to describe first the details of the exposures of Lower Lias.

(A) Lower Lias.

Detailed descriptions are first given of the sections at the Clandown Colliery Quarry, Hodder's Quarry (Timsbury), and Wellsway Quarry (Radstock), since these three exposures show different developments of the succession. A much briefer account is then given of some thirty other exposures.

(1) Clandown Colliery Quarry (fig. 3). 220 yards south of Holy Trinity Church, Clandown, Radstock.

Fig. 3.—Diagrams of exposures of the Lower Lias at places along a line running nearly due north and south.



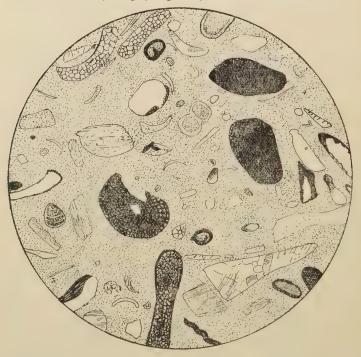
	Thickness in	feet	t inche	S.
Striatum Clay.	Greyish-green shale	2	0	Liparoceras sp., rare.
Valdani Lim'e-	Hard splintery limestone,			(Acanthopleuroceras sp.
stone.	about	1	0	and Tragophylloceras
				ibex.
				d. Tropidoceras sp. and
Jamesoni	Coarse-grained ironshot			Tragophylloceras spp.
Limestone.				
Limestone.	limestone, weathering			c. Uptonia jamesoni and
	brown, in irregular			U. cf. margata.
	beds	4	0	b. Platypleuroceras spp.,
				Uptonia sp., and Rad-
				stockiceras sp.
				(a. Polymorphites spp.
Armatum	Shelly or crinoidal lime-			(Apoderoceras sp., Belem-
Bed.	stone	0	6-8	nites.
	Sandy marl or shale	0	1-3	Pleuromya sp.
	Coarse limestone, with			(Apoderoceras leckenbyi,
	dark phosphatic nod-			Echioceras spp. (de-
	ules	0	8-10	(rived), many gastropods.
Raricostatum	Dark shale	0	1-3	Echioceras cf. zieteni.
Clay.	Data shale	0	χ υ	(Arnioceras cf. hartmanni
Obtusum	Fairly persistent, blue,			(Hyatt non Oppel),
Nodules.		0	2-3	Xipheroceras spp., and
Nountes.	fine-grained limestone.	U	2-0	
<i>m</i> + 0.3	D. J. 1.1	-	- 1	Asteroceras spp.
Turneri Clay.	Dark shale	1	1	Arnioceras spp., Arietites
				turneri.
	37 3 3 3 3 3 101			Euagassiceras spp., Agas-
Spiriferina	Nodule-band, with many			siceras scipionis, Para-
Bed.	derived fossils	0	1-2	coroniceras trigona-
				tum, P. gmuendense,
Bucklandi	Limestone with derived			Megarietites meridion-
Bed.	nodules, continuous			alis, Coroniceras spp.,
	with the bed below	0	2	Spiriferina walcotti,
				Pleurotomaria sp.
Planorbis	Fine-grained grey lime-			•
Bed.	stone	0	7	Ostrea sp.
2040	Shale, with impersistent			
	limestone	0	6	
	Limestone, coarse, ironshot	0	4	Ostrea liassica.
	Hard shale	0	2	
	Pink limestone, coarse	0	4	Ostrea liassica and echi-
	Hard shale	0	2	noid spines.
				Liford spines.
WHITE LIAS, with	the Sun-Bed at the top	18	0	

The Sun-Bed of the White Lias at Clandown is succeeded, as in many other exposures at Radstock, by hard shales with pink crystalline limestones, the 'Corn Grits' of the quarrymen. They generally contain few fossils except Ostrea liassica, which is occasionally abundant, and some echinoid spines. The succeeding limestones, which also contain Ostrea liassica, are grey in colour, and are generally finer in grain than the Corn Grits. No trace of ammonites of the Planorbis Zone has been found at Clandown, and the limestones presumably represent the Ostrea Beds (pre-Planorbis Beds) of other areas, the Planorbis Beds having been removed. There is no evidence of the Pleuromya-tatei Beds below the Ostrea Beds.

The Ostrea Beds are succeeded at Clandown by a limestone with phosphatized ammonites of the Bucklandi Zone, which rests with no visible discordance on the beds below. It is remarkable that the derived Arietidan ammonites in this bed include representatives of not less than six hemera, as distinguished by one of us

(J. W. T.) at Keynsham. The same fossils are found in the Spiriferina-walcotti Bed, which is really the lower and very fossiliferous portion of the Turneri Clay. The Spiriferina Bed is generally full of fossils, including great numbers of phosphatized and fresh Spiriferina walcotti, also many ammonites, among which species of *Euagassiceras* are most abundant.

Fig. 4.—The Ironshot Limestone (Jamesoni Limestone), Kilmersdon Road Quarry (10, p. 510). ×20. See also p. 604.



In the overlying Turneri Clay fossils are less common, and frequently are badly preserved; casts of the body-chambers of small ammonites, chiefly Arnioceras spp. and Arietites turneri, are found. The corresponding clays in the Timsbury neighbourhood are rich in foraminifera (Moore, 1867, p. 473), but comparatively few foraminifera have been detected at Clandown.

The Obtusum Bed is a thin deposit of hard blue nodular limestone, weathering on the outside to a bright vellow; it contains many ammonites, chiefly Arnioceras cf. hartmanni and small allied forms, Xipheroceras cf. planicosta and Asteroceras cf.

smithii.

The overlying shales are thin at Clandown, but a fragment of a crassicostate Echiocerate has been found in them.

Fig. 5.—Section of the White Lias and the Blue Lias seen in the quarry and a well at Rockhill. (See p. 607.)

		Jamesoni Limestone
		Armatum Bed
		Obtusum Nodules
		Turneri Clay
		-
		Bucklandi Bed
		Planorbis Zone
		Sun Bed
		"Best Bed"
		White Clay, very fossiliferous
45		"Second Best Bed"
LIAS		Lower Limit of Working
WHITE		Erregular grey limestones and hard marls
	XXXX	Nodular limestone Mottled Clay Blue-grey limestones
		Fossiliferous Blue Clay
	PAT FINA	Cotham Marble
	[Approxim	ate vertical scale: 1 inch=5 feet.

[Approximate vertical scale: 1 inch=5 feet.]

The Armatum Bed is an important fossil band. It is a pale limestone, with numerous derived fragments of a darker limestone, which are mainly found near the base of the bed. It contains many large specimens of Apoderoceras leckenbyi and other Derocerates, while the derived nodules include innumerable specimens of Echioceras raricostatoides and other species of Echioceras. The bed also contains many specimens of large oxycone Arietids, chiefly Victoriceras victoris and allied species. These are not generally surrounded by the dark matrix characteristic of the other derived specimens; but, from the nature of the material in the body-chambers, it is likely that most of them have been derived. This band is also rich in gastropods, particularly Pleurotomaria, Trochus, and small Cerithium-like forms.

The Jamesoni Limestone, known locally as the Ruckle Bed, is irregularly bedded, and always when exposed has a brownish colour; a fresh surface is paler, with dark-brown spots. In thin section the limestone is seen to be almost wholly made up of echinodermal and shelly fragments in a cloudy matrix of fine-grained calcareous material. The echinodermal remains, particularly the echinoid-spines, are frequently replaced by limonite, but occasionally replacement has affected the shelly material also

(fig. 4, p. 602).

Within the Jamesoni Limestone several ammonite faunas are represented, the sequence of which is indicated broadly in the descriptive section (p. 601). Species of Polymorphites, and especially P. lineatum, are found throughout the lowest 2 feet of the limestone, accompanied by Platypleuroceras rotundum at 1 foot above the base and P. brevispina a few inches higher. Radstockiceras complicatum has been collected at about this horizon. Uptonia jamesoni occurs within the succeeding foot or so of limestone, and 3 feet above the base it is accompanied by Uptonia margata and U. regnardi. Owing to the condensed nature of the deposits, and the absence of any change of lithology within the group, a more exact interpretation of the succession has not been possible. Numerous other species of ammonites have been collected from material quarried from these beds: these are noted in the tables of fossils (pp. 646-50); but, as their precise position can only be inferred, no detailed reference is made to them here.

Belemnites are also common in these beds, with great numbers

of Pholadomya ambigua 1 and Gryphæa cymbium.

(2) Hodder's Quarry, Timsbury² (fig. 3, p. 600).

A well-known quarry, on the east side of the road leading into Timsbury from Radstock, 500 yards south 70° east of Timsbury Church.

The exposure is to some extent comparable with that at Clandown, save that (i) the *Armatum* Bed is not represented at Timsbury; (ii) the *Bucklandi* and *Angulata* Zones are thinly

¹ G. B. Sowerby, 'Mineral Conchology' 1819, pl. cexxvii, fig. 1 only.
² Since the above was written, this quarry has changed owners, and a new quarry has been opened in the neighbourhood by Mr. Hodder.

Tragophylloceras wechs-

jamesoni, sp., Poly-; many Gryphæa ved Echiocostatoides techioceras

represented; (iii) the clays above the Spiriferina Bed are thicker; and (iv) the Jamesoni Limestone is thinner than at Clandown,

but appears to contain the same faunas.

The section at Timsbury has been open for many years, and a vast amount of material has been collected from it by numerous palæontologists. The chief fossil band is the *Bucklandi* Bed, from which many thousands of specimens have been cleaned out by Mr. Job Hodder, to whom palæontologists of several generations have been indebted for much help.

Thickness in feet inches.

The succession is as follows:—

Limestone.	Rubbly brown limestone, with derived nodules at the base		0 <	leri, Uptonia Tropidoceras s norphites sp. Belemnites; cymbium. Deriv
Raricostatum	Derived nodules	0	1 -	cerates. <i>Echioceras rario</i> (derived), <i>Lept</i>

O Tay.		Dark shales, with derived fossils		6	(Echioceras cf. zieteni, E (Echioceras cf. zieteni, E (cf. microdiscus. (Arnioceras cf. hartmanni
Obtusum	Bed.	Hard, blue, nodular lime- stone (Obtusum nodules)	0	3	Asteroceras spp., Xiphe- roceras planicosta, X.du dressieri, Cymbites lævi
		Dark shale	1	0	gatus, fish-scales.

	Hard band in shale	0	2	Arnioceras hartmanni, Asteroceras sp.
Turneri Cla	ay. Dark-blue shale, with bands of comminuted shelly materialabout		0	Arietites turneri (frag- ments), Arnioceras bod- leyi, and other species; foraminifera.

Spiriferina Bed.	Nodule-Bed, much derived material	(valcotti, Eua- spp., Arnio-
Rughlandi	Massiva musy limestone		ceras spp.	7-77 1

Bed.	Massive grey immestone, with many derived fragments, especially near the top	1 2 <	gigantea, Spiriferina
			walcotti, Pleurotomaria

	Shale	0	1
ngulata Zone.	Fine-grained grey lime-stone		Schlotheimia ef. gallica, Radula hettangiensis, Plagiostoma gigantea.
	Shale	U	1-4 Ornithella sarthacensis.
	Dark-grey limestone	0	3-8 Schlotheimia sp., Plagio- stoma dunravenensis (Tawney), Hinnites

Planorbis	Shales, with nodule-band .	0	3	Ornithella sp.
Zone.	Grey limestone	0	4	{ Psiloceras cf. planorbis Ps. plicatum,
	Shale, with nodule-band	0	4	C 13. pooluoum.

limestones	2	3 Psilocero	stoma sp.
Shale and grey limestone,	0	6 Ostrea li	assica.

Pink crystalline limestones and shales 0 10 \begin{cases} O. \ liassica, \ Myoconcha \ psilonofi \ (Quenstedt). \ Bone-fragments. \end{cases}

The chief fossil-bed at Timsbury is the massive blue limestone called here 'the Bucklandi Bed', which immediately underlies the Spiriferina Bed. This limestone contains innumerable specimens, both large and small, of Arnioceras spp. and Euagassiceras spp., often exhibiting a nacreous lustre. The absence from Timsbury of the ammonites characteristic of those horizons in the Bucklandi zone which come below Euagassiceras is noteworthy, and contrasts in a striking manner with the occurrence of phosphatized representatives of some six hemeræ in the corresponding bed at Clandown and elsewhere. Apparently, no deposition took place

at Timsbury during several of those hemeræ.

The Timsbury succession shows a greater thickness of Turneri Clay and of Obtusum Beds than any other exposure now open; the Obtusum Beds at this place include, not only the nodules, but also the clay and the hard bed immediately below. This section also shows the sequence in the Echioceras faunas more clearly than the sections farther south; Echioceras cf. microdiscus occurs welded to the top of Obtusum nodules, while several species of Leptechioceras near L. macdonnellii are found in the upper part of the Raricostatum Clay, along with derived specimens of raricostate forms. No evidence of higher members of the Echioceras faunas (aplanatum) has been obtained from Timsbury, and the Deroceras faunas are also wanting.

(3) Wellsway Quarry, Radstock (fig. 3, p. 600).

A disused quarry, entered from Wells Road; 150 yards west of Radstock Church.

This quarry shows no beds higher than the Bucklandi Zone, and is remarkable for the relatively full development of the Planorbis and Angulata Zones. The quarry has not been worked for many years, and the upper beds are not accessible; the succession may be summarized as follows:—

	Thickness in	feet	inche	S.
Bucklandi Zone.	Grey nodular limestones and shales about	_		Paracoroniceras cf. gmu- endense, Euagassiceras sp., Arnioceras sp., Rhyn- chonella sp., Spiriferina walcotti, Zeilleria sp.
Angulata Zone.	Two thick beds of grey lime- stone, with thick shale More or less nodular lime- stone, in fairly regular	1	6 {	Gryphæa aff. incurva. Ornithella sarthacensis, Gryphæa aff. obliquata. Schlotheimia stricklandi, Schl. cf. acuticosta, Schl.
	beds, with thin shaly partings	10	0 {	cf. gallica, Alsatites la- queolus, Ostrea irregu- laris, Ornithella sartha- censis, Rhynchonella sp., and Pecten cf. calvus.
	Nodular limestones and thicker shales	1	8	Ostrea sp., Hinnites angu-
Planorbis Zone.	More or less nodular, fine, grey limestone, with thin shales about Thick and regular beds of	7	0	Caloceras tortile, Psiloceras sp., and Pholadomya sp.
	crystalline limestone,		0	Ostrea liassica, Plagio- stoma dunravenensis.

The development of the *Planorbis* Zone is comparable with that seen in several parts of the district, but nowhere else south of Farmborough has so thick a development of the *Angulata* Zone been observed. The ammonites of this zone, however, indicate only the lower part of the zone (*liasicus*), and as no trace of the lowest portion of the *Bucklandi* Zone is known, it is certain that there is a non-sequence of considerable extent at that horizon.

It will now be sufficient to summarize briefly the succession in the remaining exposures of Lower Lias, indicating merely the thickness of the divisions, except in those cases where features may be noted which are not seen in the quarries just described.

(4) Tyning Colliery Quarry (fig. 3, p. 600). (900 yards north-east of Radstock Church.)

The succession is similar to that at Clandown; the Jamesoni Limestone is well exposed. The Armatum Bed includes a thin band of sandy marl, containing fish-scales and teeth, many belemnites and brachiopods, and fragments of a slender crinoid. Layers of small quartz-pebbles are also present. Large Derocerates are found both above and below the band of marl.

The *Turneri* Clay is very thin, while the *Planorbis* Zone is thicker than at Clandown, the *Ostrea* Beds being followed by beds

yielding Psiloceras and Caloceras.

Thickness in		inches.
Striatum Clay, exposed	1	0
Valdani and Jamesoni Limestones	6	3
Armatum Bed	2	7
Raricostatum Clay	0	2
Obtusum Nodules	0	3
Turneri Clay and Spiriferina Bed	0	2-4
Planorbis Zone	5	6
WHITE LIAS.		

(5) Rockhill Quarry (fig. 5, p. 603).(80 yards south of Rockhill Cottages, Clandown.)

This is situated very near to Clandown Quarry, and the succession is comparable, differing only in the thicker development of the *Planorbis* Zone; at Clandown the *Spiriferina* Bed rests directly on the *Ostrea* Beds, but at Rockhill, as at Tyning Colliery, the overlying *Planorbis* Beds and *Caloceras* (johnstoni) Beds are present.

Thickness in		
Jamesoni Limestone exposed	4	0
Armatum Bed	2	0
Raricostatum Clay	0	3
Obtusum Nodules	0	3
Turneri Clay, with Spiriferina Bed	1	0
Bucklandi Bed	0	5
Planorbis Zone	5	3
WHITE LIAS.		
Q. J. G. S. No. 324.		2 s

In this quarry one of us had an opportunity, some years ago, of examining the complete succession of White Lias, down to the Cotham Marble at the top of the Rhætic, in a well-section dug by Mr. G. Denning. A total thickness of 182 feet of White Lias was proved. Details of the sequence are shown in the accompanying diagram (fig. 5, p. 603).

Two beds of limestone in the White Lias are especially used for building purposes, the Best Bed and the Second Best Bed. A bed of white laminated clay 7 inches thick, 71 feet below the Sun-Bed, is very fossiliferous; it is constant over a wide area, and has been

observed at Paulton and at Tyning Farm.

The lowest 8 feet of the White Lias consists of thin irregular limestones with clay-partings; these are of little economic value, and therefore are rarely exposed in the quarries. Immediately above the Cotham Marble is a bed of blue clay 14 inches thick, containing fossils characteristic of the White Lias.

The fossils recorded from the White Lias (Langportensis Beds)

include :-

Chemnitzia (Zygopleura) cf. fistulosa Stoliczka. Phasianella liasina Terquem.

Zygopleura sp.

Astarte cf. irregularis Terquem. Astarte cf. thalassina Quenstedt. Cardinia cf. moreana Martin. Cardinia sublamellosa Martin. (?) Cypricardia winwoodi Moore. Dimyodon intusstriata (Emmerich). Gervillia præcursor Quenstedt. Isocardia sp. Dumortier (' Bassin du Rhône 'pt. i, pl. iii, figs. 5 & 6). Lima cf. terquemi Tate. Lima valoniensis (Defrance) Du-

Macrodon cf. hettangiensis (Terquem). Macrodon lycetti (Moore). Opis sp. nov.

Ostrea liassica Strickland.

Pecten pollux A. d'Orbigny. Pholadomya prima Quenstedt, Dumortier.

Pleuromya escheri (Winkler, Du-

mortier). Pleuromya langportensis Richard-

son & Tutcher. Plicatula hettangiensis Terquem.

Plicatula sp. Protocardia phillipsiana (Dunker).

Pseudomonotis decussata (Münster). Volsella (Modiola) langportensis Richardson & Tutcher.

Diademopsis tomesi (Wright).

Montlivaltia sp.

Otozamites obtusus Lindley & Hutton.

(6) Bowldish (or Bold Ditch) Quarry.

(At the junction of Bold Ditch Lane and Water Lane, two-thirds of a mile due west of Clandown Quarry.)

This quarry shows a greater thickness of Turneri Clay than is seen in any quarry nearer Radstock. The Planorbis Beds are thinly represented, the junction of the Bucklandi Zone and Planorbis Zone occurring obscurely in the middle of a massive limestone, below the Spiriferina Bed with its derived fossils, where a non-sequence might have been expected.

Thickness in	feet	inches.
Armatum Bed, with nodular base		$0 \left\{ egin{array}{l} Phricodoceras lamellosum, \ Echioceras sp., Victoriceras victoris. \end{array} ight.$
Raricostatum Clay: Clay	0	4 ceras victoris.
Limestone	0	3 { Microceras subplanicosta, Echioceras spp.
Clay	0	10 Belemnites oxyconus.
Obtusum nodules		5 { Xipheroceras planicosta, and fish-scales.
Turneri Clay, with Spiriferina Bed	1	6 { Belemnites cf. acutus Phil- lips non Miller.
Bucklandi Bed, with eroded top	0	8 Arniocoras spp., Euagassiceras spp., Agassiceras scipionis, and Paracoroniceras sp.
Planorbis Zone: limestones and shales (upper limestone continuous with the Bucklandi Bed) WHITE LIAS.	3	niceras sp.

(7) Bince's Lodge Quarry (fig. 6, p. 612). (An old quarry at Bince's Lodge, north of Midsomer Norton.)

The succession in this quarry is similar to that just described in the Bowldish Quarry, 400 yards away to the north-east. The Raricostatum Clay and the Turneri Clay are thinner than at Bowldish.

	Thickness in		inches.
Jamesoni Limestone	exposed	1	0 { Pecten liasinus and many brachiopods.
Armatum Bed: Creamy ironshot lin			6 { Deroceras sp.; many gastropods.
Sandy crinoidal mar Soft ironshot lim	estone, with	0	10 Belemnites sp.
Raricostatum Clay: clay, with frag		0	10
rived limestone		0	$9 \begin{cases} Belemnites & o.vy-\\ conus. \end{cases}$
7) busum nodules		0	4
Turners Clay, with Spirifering Red		1	3
Planorbis Zone	**************	T.	
WHITE LIAS.		1	11

(8) Welton Hill Quarry.

(An old quarry, now largely overgrown, on Welton Hill, near the Isolation Hospital.)

The exposures showed nothing higher than the *Planorbis* Zone, but ammonites were present within the lowest few feet, and the *Ostrea* Beds were thin.

(9) Middle Pit.

(A disused quarry, now overgrown, near Middle Pit Colliery, about 600 yards west of north of Radstock Church.)

The succession seen here was almost identical with that at Wellsway (no. 3, p. 606).

	Thickness in	feet	inches.
Bucklandi Zone		2	0
Angulata Zone	about	13	0
Planorbis Zone		9	0
WHITE LIAS.			

(10) & (11) Kilmersdon Road Quarries (fig. 3, p. 600). (Two quarries south of Radstock and west of the road to Kilmersdon.)

The quarry nearer Radstock, 440 yards south of the church, is called Radstock Grove in some papers. The other is at the

corner of the road near Kilmersdon Colliery.

The succession is so similar in the two exposures that they do not need to be separately described. In each of them the clay group (the *Raricostatum* and *Turneri* Clays) is thinner than at Clandown and in the quarries north of Radstock, while the zones below the *Spiriferina* Bed are fairly well developed; the *Planorbis* Zone is represented by *Ostrea*, *Planorbis*, and *Caloceras* Beds, and is followed by a thin development of the *Angulata* Zone.

	Thickness in	feet	inches.
Jamesoni Limeston	e exposed	5	0
Armatum Bed		2	()
			1
Obtusum Nodules		0	3
Turneri Clay, with	Spiriferina Bed	0	2
Angulata Zone	about	1	6
Planorbis Zone .		8	6
WHITE LIAS.			

(12) Bird's Quarry (formerly called Ludlow's Quarry). (About 400 yards east of Radstock Church.)

The thickness of the *Planorbis* Zone is approximately the same as that seen in the Kilmersdon Road quarries, but this quarry is remarkable for the attenuated development of the clay group, much of which has apparently been removed, with some of the underlying beds, before the deposition of the *Armatum* Bed, which frequently rests upon an eroded surface of the *Planorbis* Zone. Occasional fragments of the *Obtusum* Nodules may be seen along the plane of erosion, suggesting that the conditions are to be explained by subsequent erosion rather than by non-deposition.

Thickness in	feet	inches.
Jamesoni Limestone	4	0
Armatum Bed		6
Disturbed clay, with fragments of Echio-		
ceras and Asteroceras	0	1
Planorbis Zone about	6	6
WHITE LIAS.		

(13) Huish Colliery Quarry.1

(300 yards north-west of the Huish Colliery, south-east of Radstock. This quarry has been variously known as Branch Huish, Foxhole, and Writhlington.)

A photograph of this quarry is given in L. Richardson's (1910) paper, pl. x.

In this quarry the clay group is even more scantily represented than in Bird's Quarry, for the Armatum Beds rest directly on the Planorbis Zone. The Jamesoni and Valdani Limestones are well seen, with the Striatum Clays above; these are succeeded by rubbly Inferior Oolite limestones. Apparently, the thickness of the Striatum Clay is only about 8 feet, but the situation of the quarry on the valley-slopes makes it possible that part of the clay has been covered by a slip of oolite.

Tnickness in Inferior Oolite limestone, with Acantho-	feet	inches
thyris spinosa, Trigonia sp., Pecten sp.,	0	0
and Montlivaltia sp seen Striatum Clays: at the base, Liparoceras	2	0
sparsicosta	8	0
Valdani Limestone	1	0
Jamesoni Limestone	4	0
Armatum Bed	1	6
Planorbis Zone	4	6
WHITE LIAS.		

(14) Chapel Quarry.

(A disused quarry, west side of Radstock, between the Fosse Way and the Midland Railway; 220 yards north of the Methodist Chapel on Wells Road.)

In general character, the sequence is similar to that in Bird's Quarry; the clay group is represented by only a few inches of disturbed clay, which rests on the *Planorbis Zone (Caloceras Beds)*.—The higher part of the *Jamesoni Limestone*, with the *Valdani Limestone* and the *Striatum Clay*, was only seen in a narrow faulted area.

Thickness in	feet	inches
Striatum Clay visible	1	0
Valdani Limestone	1	0
Jamesoni Limestone	4	0
Armatum Bed	1	6
Disturbed clay, with Obtusum nodules and		
derived Spiriferina and Gryphæa	0	2-6
Planorbis Zone	6	6
WHITE LIAS.		

(15) Westfield Quarry (fig. 6, p. 612).

(A disused quarry, west of Radstock, 270 yards south-east of the Elm Tree Inn, Westfield.)

The succession is similar to that at the Chapel Quarry, but the *Planorbis* Zone is thicker, although the *Angulata* Zone is still unrepresented.

Thickness in	feet	inches.
Jamesoni Limestone	4	0
Armatum Bed	1	6
Clay, with Obtusum nodules, Euagassiceras		
sp., and Spiriferina walcotti	0	6
Planorbis Zone	10	0

(16) Tyning Farm Quarry (fig. 3, p. 600). (A disused quarry, 200 yards south of Tyning Farm, and about a mile south of Radstock.)

This quarry shows a succession similar to that just described. The clay group is scarcely represented, except by a thin disturbed clay which fills the hollows in the bored and eroded surface of the *Planorbis* Zone; this surface was probably worn in post-obtusi time, and all the zone, with the exception of the *Ostrea* Beds, has been removed.

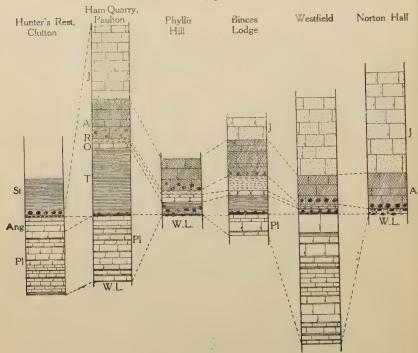
Thickness in feet inches.

11000000000	,,	
Jamesoni Limestone, with Tragophylloceras		
sp. and Uptonia spp	3	0
Armatum Bed, with abundant Derocerates	1	6
Irregular clay, with phosphatic nodules	0	1-2
Planorbis Zone	2	6

(17) Norton Hall Quarry (fig. 6, below).

(A quarry on the Fosse Way, 550 yards south of Norton Hall, and about a mile and a half south of Midsomer Norton.)

Fig. 6.—Diagrams of exposures of the Lower Lias at localities along a line running nearly due north and south, west of the sections illustrated in fig. 3, p. 600.



[Approximate vertical scale: 1 inch = 6 feet.] For explanation of lettering, see fig. 3, p. 600

In this quarry the succession in the upper beds is normal, but the clay group is again represented by only a few inches of deposit, containing many derived fossils. The clay rests directly upon the White Lias, which is not of the usual type, being harder and more siliceous; it is presumably of more nearly littoral character than the White Lias farther north, and may be compared with some of the littoral developments of the Lias in Glamorgan.

Thickness in	feet	inches.
Jamesoni Limestone	4	0
Armatum Beds	1	6
Clay with derived Echiocerates, Arnioceras		
spp., Spiriferina cf. walcotti (possibly a		
later species)	0	2-3
WHITE LIAS.		

It may be noted that at Hemington, $2\frac{1}{2}$ miles east-south-east of Radstock, a boring for coal showed that the *Jamesoni* Limestone rests directly upon a bored and uneven surface of the White Lias (T. C. Cantrill & J. Pringle, 1914), which, with the evidence of the quarries at Tyning Farm, Huish, and Norton Hall, indicates that the sequence becomes less complete southwards.

(18) Vobster.

The Lias of Vobster has been described by several authors.\(^1\) A full account of it is not included here, but it will be useful to discuss the relations of the Lias at Vobster with that at Radstock.

In the present exposures at Vobster, the large quarries 500 yards north of Upper Vobster Farm, 3 or 4 feet of brown-stained rubbly limestone are seen resting upon a remarkably smooth and flat denuded surface of Carboniferous Limestone. The Liassic limestone is coarsely crystalline, often ironshot, and represents the Armatum Bed and the Jamesoni Limestone of Radstock.

In the lower part, varying in thickness from 6 to 12 inches, are numerous Derocerates and Arietidan oxycones (Victoriceras) with derived Echiocerates. These latter include mainly species of Arietidan aspect, with keels and straight ribs, such as Metechioceras aplanatum and Eucchioceras nobile. Gastropods are common in this lower portion, with simple corals (Montlivaltia rugosa Duncan). These lower limestones contain some dark phosphatized nodules derived from older deposits, although no other trace of such deposits is seen in the present exposures; traces of deposits which may represent the Rhætic and Hettangian have been noted at Vobster by Mr. L. Richardson, and it is probable that several sets of deposits were laid down on the Carboniferous

¹ The most useful accounts are by Mr. L. Richardson (1909 & 1910) and Prof. S. H. Reynolds. Photographs are given in a paper on the Carboniferous Limestone, by Principal T. F. Sibly, Q. J. G. S. vol. lxviii (1912) pl. iv, fig. 1.

Limestone platform and were subsequently removed during periods of slight uplift, before the deposition of the *Armatum* Bed.

The overlying limestones represent the Jamesoni Limestone, and contain Polymorphites spp. and Platypleuroceras spp.

(19) Stony Littleton Quarry. (A small quarry south of the railway at Stony Littleton, about a mile north-east of Foxcote.)

In this quarry, situated some distance east of any exposures that we have described, the *Planorbis* and *Angulata* Zones are fairly thick We did not observe any trace of the *Obtusum* nodules, the *Raricostatum* Clay, or the *Armatum* Bed in this exposure, but the sequence in the upper beds is somewhat obscure.

The Bucklandi Zone includes derived ammonites from the lower horizons of the zone (such as bisulcate species of Coroni-

ceras), as well as Euagassiceras spp.

	Thickness in feet	inches
Jamesoni Limestone	2	. 0
Turneri Clay	2	0
Bucklandi Zone		6
Angulata Zone	9	8
Planorbis Zone	5	0

It may be useful to summarize here the general characters of the Lias seen in the quarries around Radstock. With the exception of Wellsway and Middle Pit, where the sections show a relatively thick development of the Planorbis, Angulata, and Bucklandi Zones, but no higher beds, all the exposures show a similar succession of the Valdani and Jamesoni Limestones and Armatum Bed. The clay group (Raricostatum and Turneri Clays, with the Obtusum nodules) is always thin in the Radstock neighbourhood; but the sequence within it is usually clear, except in the southernmost quarries, where the group is attenuated and generally disturbed.

The variations in thickness in the beds below the *Turneri* Clay are much less regular; in general, they are thickest in the immediate neighbourhood of Radstock, becoming thinner northwards and southwards. This is partly due to the denudation (preturneri hemera, probably pre-sauzeanum) which has removed the

Angulata and Bucklandi Zones over a wide area.

Quarries near Paulton.

(20) Ham Quarry, Paulton (fig. 6, p. 612). (600 yards south-east of Paulton Church.)

In this extensive exposure the sequence from White Lias to *Turneri* Clay is now visible; but a temporary exposure north of an east-and-west fault showed the succession in the overlying beds. The *Turneri* Clays are much thicker than those at Radstock, and are more nearly comparable with those at Timsbury.

Thickness in	feet	inches,
Striatum Clay	1	0
Valdani Limestone	1	6
Jamesoni Limestone	4	6
Armatum Bed, with a bed of sandy marl	2	0
Raricostatum Clay, irregular	0	2
Obtusum Nodules	0	5-8
Turneri Clay, with Spiriferina Bed	4	0
Planorbis Zone (Planorbis and Ostrea Beds)	4	6
WHITE LIAS.		

(21) Newtown Quarry, Paulton. (A disused quarry, 300 yards south-55°-west of Paulton Church.)

The succession here is similar to that in the quarry just described, except that the Turneri Clay is much thinner.

9	Thickness in	feet	inches.
Jamesoni Limestone		2	0
Armatum Bed		1	6
Raricostatum Clay		0	2
Obtusum Nodules		0	5
Turneri Clay, with Spiriferina I	Bed	0	10
Planorbis Zone		4	3
WHITE LIAS	exposed	8	0

It may be noted that one of us (J. W. T.) was able to determine that the White Lias at this place consisted of massive white limestones, down to a depth of about 8 feet below the Sun-Bed, at which depth they are underlain by the thick fossiliferous clay that occurs at about the same horizon at Rockhill (No. 5, p. 607).

(22) The Batch Quarry, Paulton.

In a temporary exposure, 270 yards south of Paulton Church, a thickness of about $4\frac{1}{2}$ feet of *Planorbis* Zone was exposed, underlain by 7 feet of White Lias limestone.

(23) Winterfield Quarry, Paulton.

(A temporary quarry, seen in 1920, some 850 yards south-east of Paulton Church, behind a factory east of the road at Winterfield.)

The section was similar to that at the Ham Quarry, except that the Turneri Clay is thin, and the Bucklandi Bed rests upon a thin and obviously eroded representative of the *Planorbis* Zone.

Thickness in	feet	inches.
Armatum Bed exposed	1	0
Raricostatum Clay	0	8
Obtusum Nodules	0	1-2
Turneri Clay, with Spiriferina Bed	1	6
Bucklandi Bed, with Gryphæa and Eu-		
agassiceras	0	4
Planorbis Zone (Ostrea Beds)	1	4
WHITE LIAS	7	0

(24) Phyllis Hill Quarry, Paulton (fig. 6, p. 612).

(West of the road leading to Midsomer Norton, three-quarters of a mile south-35°-east of Paulton Church.)

A large quarry formerly worked at this place has long been

overgrown, but a small section has recently been reopened.

The uppermost beds are not seen, but thin disturbed *Turneri* Clays with many derived fossils rest upon an eroded surface of White Lias; in other words, proceeding southwards from Paulton the thickness of the *Planorbis* Zone lessens. The section may, therefore, be compared with that at Norton Hall (No. 17, p. 612).

Thickness in	feet	inches
Armatum Bed	1	0
Raricostatum Clay, with thin limestone	0	2
Obtusum Nodules, limestone	0	2
shale	0	1
limestone	0	5
Turneri Clay, with many derived fossils		
(Euagassiceras, Agassiceras scipionis,		
Arnioceras sp.)	0	10
WHITE LIAS, upper surface eroded	7	0

From information concerning a well-section at this place, received from Mr. W. J. Ashman, it appears that the thickness of White Lias is approximately the same as that at Rockhill.

(25) Mungar Quarry, Paulton.

(A disused quarry on Mungar Lane, midway between Midsomer Norton and Paulton, and about 300 yards east of the quarry at Phyllis Hill.)

This quarry was described by Moore (1867, p. 474), Tate (1875, p. 500), and H. B. Woodward (1893, p. 130); but the exposure has been almost completely overgrown for many years. From the details given by the above-named writers, however, it appears that the succession is approximately the same as that at Phyllis Hill.

The Valdani Limestone is well represented in the quarry, and from it one of us (J. W. T.) has obtained Tragophylloceras ibex, Tr. wechsleri, Acanthopleuroceras spp., and Kallilytoceras inter-

lineatum.

It may be noted here that the evidence derived from the study of the quarries near Paulton confirms the conclusions arrived at concerning the variations in the sequence around Radstock. The variations result mainly from (1) the attenuation southwards of the Raricostatum Clays and the Turneri Clay; and (2) the differing degrees of erosion of the Planorbis and Angulata Zones before the deposition of the Spiriferina Bed.

Quarries near Timsbury.

(26) Camerton Quarry.

(An old quarry a quarter of a mile north-north-east of the church, long disused.)

The section was described by Moore (1867) and H. B. Woodward (1893, p. 131), but is now quite overgrown. The section is apparently similar to that at Timsbury, the Armatum Bed being absent; the Turneri Clay (according to Moore) is 8 feet thick, and therefore is much thicker than at Timsbury. It is also rich in foraminifera. On the other hand, the limestones below the Spiriferina Bed appear to be much thinner than at Timsbury.

(27) Convgre Quarry, Timsbury. (A disused quarry, 300 yards south-east of Hodder's Quarry.)

The section is similar to that at Hodder's Quarry.

Thickness in	feet	inches.
Turneri Clay, with Spiriferina Bed	2	0
Bucklandi Bed, with derived nodules, about	2	0
Angulata Zone	1	6
Planorbis Zone	5	6

(28) Exposures near Dunkerton Colliery.

No exposures are at present to be seen in this neighbourhood, but a series of sections was observed by one of us (J. W. T.) during the construction of the Great Western Railway branchline at Dunkerton, and in some old quarries; the positions of these exposures are shown on the map (fig. 8, p. 623). The Upper Lias was exposed in the railway-cutting, and is described later. The Lower Lias was similar in general characters to that at Timsbury; but, as at Camerton, a much greater thickness of the Angulata Zone was observed, while the Bucklandi Bed contains a more varied series of Arietids.

Thickness in	feet	inches
Valdani Limestone	1	0
Jamesoni Limestone, yellow limestone	3	0
Grey limestone, with derived Echiocerates	0	2
Raricostatum Clay	0	6
Obtusum Nodules	0	1-2
Turneri Clay	8	0
Bucklandi Bed, with Spiriferina, Agassiceras, Euagassiceras, Paracoroniceras	2	0
Angulata Zone, limestones and shales, with Schlotheimia depressa, Schl. striatissima, Schl. acuticosta, Spiriferina pinguis, and	4 5	0
Ornithella sarthacensis	15	0
Planorbis Zone, with Caloceras, Psiloceras, and Ostrea liassica	4	0
WHITE LIAS.		

Fig. 7.—Section of the Lias at Timsbury Sleight. [Vertical scale: 1 inch=12 feet.]

Mottled		Isastræa spp Rhynchonella subtetrahedra Frigonia cf. costata Dumortieria subsolans (derived) Belemnites voltzi Phil. Grammoceras edicum, expeditum Cereceras inequitin, Grammoceras toarciense Harpoceras, Hildoceras Pagestierias, Hildoceras	dispansum Struckmanni pedicum striatulum lilli spanetum
Blue micaceous clays	20 feet omitted	cí, Amblycoceras brevilobatum, Goniomya hybrida, Pecten sp., Inoceramus sp.	Capricornum
Blue clay Blue clay Greenish clays with ochreous nodules	25 feet omitted	Liparoceras cl. sparsicosta, Turbo cyclostoms, Actisonina chrysalis, Gervillia laevis, Leda galashea, L. zietem, Protocardia sp. Belemnites clavatus	Striatum
		Liparoceras sp. Acanthopieuroceras sp.	valdani
	THE WEST STORY		jamesoni raricostatoides
		Spiriferina walcotti Paracoroniceras gmuendense	turneri-obtusum bucklandı
		Radula hettangiensis	angulata
		Caloceras sp Psiloceras sp Ostræa liassica	planorbis
White Lias	1		langportensis

(29) Bloomfield Quarry, Timsbury.

(A disused quarry north of Hodder's Quarry, and half a mile north-15°-east of Timsbury Church.)

The succession is similar to that at Hodder's Quarry, but there is no trace of the *Angulata* Zone.

	Thickness in	feet	inches.
Raricostatum Clay		0	6
Obtusum Nodules		0	4-6
Turneri Clay		1	3
Bucklandi Bed		0	9
Planorbis Zone		3	0
WHITE LIAS.			

(30) Timsbury Sleight (fig. 7, p. 618).

A continuous section from the Inferior Oolite to the White Lias was measured by one of us (J. W. T.) during the construction of waterworks at Timsbury Sleight, north-west of Timsbury. Some details of the Inferior Oolite of these exposures has been published by Mr. L. Richardson (1907, pp. 413 et seqq.).

The sections showed a thin development of the Upper Lias, but no Middle Lias. It will be more convenient to describe the Upper Lias of this and other areas in a later paragraph; the succession

in the Lower Lias may be summarized as follows:—

Thick	kness in	feet	inches.
	about	75	0
	about	45	0
nes.			
Bed.			
	nes.	about	

The chief characters of the lithology and paleontology of the Lower Lias are indicated in the diagram (fig. 7, p. 618), and it does not appear to be necessary to describe them in fuller detail here.

In these quarries near Timsbury, or perhaps in all north of the Cam Brook, there is usually a thicker development of clays than near either Paulton or Radstock. The lower group of limestones (*Planorbis*, *Angulata*, and *Bucklandi* Zones) are variable in thickness, as are those farther south; the ammonites of the *Bucklandi* Zone generally include only those forms that are characteristic of horizons above *Paracoronicerus gmuendense*.

The most important feature distinguishing these exposures from those farther south, however, is the absence from them of all trace of the *Armatum* Bed. Although derived Echiocerates are present in the *Raricostatum* Clay, and sometimes in the lowest bed of the *Jamesoni* Limestone, no specimens of *Deroceras* or its

allies, or of oxycones of the genus Victoriceras, have been found in any exposures north of the Cam Brook. The absence even of derived fossils of Deroceratan date in those beds which contain derived Echioceras suggests that no deposits containing Deroceras were accumulated in this area.

(31 & 32) Farmborough Quarries (fig. 3, p. 600).

Two quarries afforded exposures of the Lower Lias in 1920. They were situated 600 yards south-east, and 300 yards east, respectively, of All Saints' Church, Farmborough.

The section in each quarry is approximately the same. They show a relatively thick development of the Angulata Zone, which probably includes higher horizons in the zone than are represented near Radstock (or indeed in any exposures in the area dealt with in this paper). The succession is most closely comparable with that at Wellsway (No. 3, p. 606), but the development of the Planorbis Zone is thinner than that at Wellsway.

Thickness in	feet	inches.
Angulata Zone: nodular limestones and shales, with		
Schlotheimia cf. gallica, Schl. acuticosta, Ostrea irregularis, Radula hettangiensis, Hinnites sp.,		
and Ornithella sarthacensis about	13	0
Planorbis Zone: grey limestones and shales, with Caloceras sp., Psiloceras spp.	2	6
Pink limestones and hard shales, with Ostrea liassica and Pleuromya tatei	2	0
and I remonify the control of the co		

(33) Hobbs Wall Quarry.

(An old quarry south of the road, a mile west-south-west of Farmborough.)

The succession is similar to that at Farmborough.

	Thickness in	feet	inches.
Angulata Zone	exposed	7	0
Planorbis Zone			6
WHITE LIAS.			

(34) Sections near the Hunter's Rest Inn, Clutton (fig. 6, p. 612).

In a quarry near the Hunter's Rest, Striatum Clays are seen resting on the eroded surface of the Angulata Zone. In the fields above the quarry is a feature formed by a band of limestone, which is poorly exposed in an old quarry east of Clutton Hill

Cottage.

Blackberry Hill, on the southern flanks of which these exposures are seen, is capped with Inferior Oolite; below this are clays weathering yellow, with nodular limestones containing Dactylioceras, and underlain by blue clays, probably representing the Capricornum Clay. These beds are poorly exposed, but may be seen in the lane leading to Upper Barrow Hill Farm.

Thickness in feet	inches.
Capricornum and Striatum Clays:	
Blue clays, with ironstone-nodules about 50	0
Dense blue limestone, with Tragophylloceras	
loscombi, Liparoceras sp., Gervillia lævis,	
Leda minor, L. galathea, Zygopleura blain-	
villei, and Turbo cyclostoma	0
Blue clays (only the lowest 2 feet exposed),	
with phosphatic nodules at the base con-	
taining Belemnites longissimus 20	0
Angulata Zone about 1	0
Planorbis Zone	9
WHITE LIAS.	

(B) Upper Lias. [J. W. T.]

The Upper Lias has been detected in the northern part only of the Radstock district: namely, north of a line from Blackberry Hill on the west to Wellow on the east. Wherever exposures have been seen south of the River Somer (Wellow valley), the attenuated deposits of the Striatum and Capricornum Clays are immediately succeeded by the Upper Trigonia Grit of the Oolitic rocks without a trace of intervening Middle or Upper Lias.

Timsbury Sleight (see also exposure 30, p. 619).

The most complete exposure was seen in 1907 in an excavation for a reservoir at Timsbury Sleight, 6 furlongs north-east of Timsbury Church. The succession was described by Mr. L. Richardson (1907, p. 413), who examined the section seen in the trial-shafts. Subsequently the completed excavation provided an opportunity for more detailed examination and for the collection of specimens in situ. The succession is as follows:—

A				
	Hemeræ.	Thickness in	feet	inches.
	(truelli.	Upper Coral-Bed, Isastræa spp		. 0
		Dundry Freestone equivalent	3	6
	garantianum.	Upper Trigonia Grit, the conglomerate-		
	3	bed; Rhynchonella subtetrahedra Da-		
VESULIAN.	₹	vidson, Trigonia ct. costata (Sowerby),		
1 200 21	1	Cucullaa oblonga Sowerby, derived,		
		Ctenostreon pectiniforme (Sowerby),		
		Astarte excavata Sowerby, derived,		
		large Perna sp., derived	0	6
	Dumortieria.	Sandy micaceous limestone, conglomer-		U
	Dumor corta.	atic in places; Dumortieria subsolaris		
		S. Buckman	0	3
	dispansum.	Yellow sands, merging downwards into	U	o o
	aispansum.	yellow sandy clay; Belemnites voltzi		
			5	0
		Phillips, B. stimulus Dumortier	9	U
	struckmanni.	Brown marl, with numerous limonite-		
		granules; Pseudogrammoceras dærn-		
		tense (Denckmann), P. quadratum		
		(Haug), Belemnites inæquistriatus		
		Simpson. B. cf. tripartitus Schlot-		
		heim, and many specimens of a small	_	
YEOVILIAN.	₹	_globose Rhynchonella sp. nov	- 1	3
	pedicum.	Limestone, brown, coarsely ironshot;		
		Pseudogrammoceras pedicum S. Buck-		
		man, Ps. pachu S. Buckman, Ps. sæ-		
		manni (Dumortier), Ps. expeditum S.		
		Buckman	0	9
	•			

	Hemeræ.	Thickness in	feet in	ches.
1	eseri.	Limestone, as above; Esericeras in-		
	60010.	æquum S. Buckman, E. fascigerum	0	9
	striatulum.	Pale-brown limestone, ironshot, with fewer grains than the overlying bed; Grammoceras penestriatulum S. Buck-		
		man Gr. toarciense (A. d'Urbighy)	0	8
	? lilli.	Limestone, similar to the preceding; Hildoceras hildense (Young & Bird), H. cf. walcotti (Sowerby), H. semipolitum		
		S Buckman, H. mulgravium (Young &		
		Bird). The infilling of these ammonites		
1		often differs from the matrix in which they are enclosed; it has a finer grain,		
		with fewer and smaller limonite-gran-		
WHITBIAN.		nles and varies in colour from yellow to		
		grevish-brown, sometimes with a pink- ish hue	0	4
	anguinum.	Pale-brown marl, not iron-hot, imper-		
		sistent: Dactylioceras cf. commune		
		(Sowerby), 'perhaps D. annuliferum Simpson' (fide S. Buckman), D. cras-		
		sulum (Simpson), and Rhynchonetta		9
(_	moorei Davidson Clay, mottled blue and yellow	0 3	3 6
CHARMOUTH-	capricornum and	Clay, blue micaceous, passing down into		
IAN.	striatum.	greenish clay with ochreous nodules,	117	0
		anout		

The absence of the Middle Lias (Domerian) was proved by a borehole put down in the floor of the excavation, and by an examination of the pipe-trench on the hillside. This trench disclosed a complete section of the Liassic deposits from the blue clay (upper Capricornum Clay) seen in the excavation to the White Lias at the base of the hill. From measurements taken there the total thickness of the greenish and blue clay of the Striatum and Capricornum Zones is estimated to be 120 feet. The only calcareous band in the upper part of these clays occurred 45 feet from the top; it consisted of thin nodules from which a specimen of Amblycoceras was obtained.

Dunkerton (see exposure 28, p. 617).

Some 2½ miles east of Timsbury Sleight the Upper Lias was seen during the making of the railway from Camerton to Limpley Stoke. At Dunkerton Colliery, a mile south-west of Dunkerton Church, the railway occupies the site of the Somerset coal-canal, in the construction of which William Smith was engaged. observations on this section are recorded by L. Richardson (1909, p. 100), H. H. Winwood (1908, p. 195) and, in more detail as regards the Lias, by H. B. Woodward (1908, p. 195). Each of these writers refers to the confusion caused by the large amount of slipping which has occurred on the hillside, especially at the eastern end of the cutting. The primary cause of the disturbed condition of the beds is believed by us to be sharp local folding seen in neighbouring sections, which may not have been available at the time of the earlier observations mentioned above.

Fig. 8.—Scale: 100 yards=0.75 inch, or 1:4800.

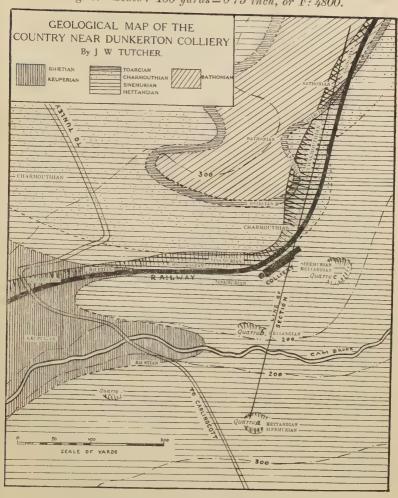
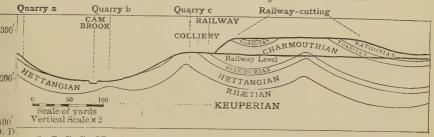


Fig. 9.—Section across the Cam Valley near Dunkerton.



The most important of these sections are indicated in fig. 8 (p. 623), as Quarries a, b, c. In each of these quarries the beds are sharply flexured, the axes of the folds trending east and west. These quarries are on a lower level than the railway; as, however, the anticline seen in Quarry crises at an angle of 4° west, the Lower Lias, Rhætic, and Trias are successively brought up to the rail-level west of the colliery. At the colliery the railway takes a northward direction, and then crosses a fourth flexure; but, as the principal deposits consist of Striatum and Capricornum Clays, folding is less obvious than in calcareous beds. It is on this section of the line that the confusion noted by earlier observers is most in evidence; blocks of Lower Oolite, Upper Lias, and Lower Lias (Jamesoni Limestone), superficially similar, were seen in juxtaposition. Some of these had slipped down the hillside; but, as a result of the folding, they also crop out at the rail-level. Since the Lower Fullers' Earth is involved, the flexuring of the rocks across the Cam Valley must be later than that deposit, but how much later there is at present no evidence to show.

The sequence tabulated below is that of the upper part of the Dunkerton Colliery section. Detailed measurement of the Bathonian was impracticable, but the total thickness of the Oolite was

estimated to be from 20 to 25 feet.

Fullers' Earth.

BATHONIAN. Pale-yellow rock; Ornithella ornithocephala auctt., O. cado-

Blue clay; Rhynchonella smithi Walker, Ostrea knorri Voltz.

mensis (Deslongchamps).

Fullers Earth.	Blue clay; Rhynchonella smithi Walker, Ostrea know	ata (De-
Anabacia	White, very colitic limestone; Anabacia complan		
Limestone.	france). Yellow limestone; Isastræa spp., Terebratula globa	ta au	ctt.,
Upper Coral- Bed.	Limatula gibbosa (Sowerby), Adulpecton sym	,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	
Upper Trigonia Grit.	(Morris). Brown oolitic ragstone; Strenoceras garantianum bigny), Rhynchonella subtetrahedra Davidson, thyris spinosa (Schlotheim), Homomya gibbosa (Schlotheim), Homomya (Sch		
	UPPER LIAS-TOARCIAN.	at in	ahae
	Thickness in fe	$\frac{3}{3}$	0
dispansum.	Yellow micaceous sands (Midford Sands) about Sandy rock, slightly micaceous in the upper part,	Э	U
struckmanni.	some iroushot stone at the base; I settle by and	1	6
pedicum.	Brown marl mixed with coarsely ironshot lime- stone, pebbles at the base; Pseudogrammoceras expeditum S. Buckman	0	3
eseri-striatulum.	expensions. State of the base; Eseri- tronshot limestone, pelbles at the base; Eseri- ceras eseri (Oppel), Grammoceras penestria- tulum S. Buckman, Gr. toarciense (A. d'Or-		
	bigny). Also many fragmentary specimens of		
	Hildoceras, Harpoceras, and Dactymoceras	1	3
	(Limestone, finely ironshot; Hildoceras hildense (Young & Bird), H. semipolitum S. Buckman,	0	8
lillî.	Pink limestone with few limonite-grains,	0	4
anguinum.	erby)	0	2
	LOWER LIAS (CHARMOUTHIAN). Capricornum and Striatum Clays about	50	0
	•		

Here, as at Timsbury Sleight, the Middle Lias is absent. In the clay underlying the Upper Lias large lenticular masses of cement-stone occur, containing fragments of capricorn ammonites. There is evidence of erosion at more than one level in the Upper Lias. The fossils in the *lilli* to anguinum zones are fairly well preserved, but those in later beds are badly preserved and often fragmentary.

Evidence of considerable erosion of the Upper Lias has been recorded by Buckman & Wilson from observations at Wellow, $2\frac{1}{2}$ miles east of Dunkerton Colliery.\(^1\) There the beds are reduced to a few fragments of \(lili\) date. Nearer Radstock, at Forscote (Foxcote) Colliery, half a mile south-west of Forscote village, and at Huish (exposure 13, pp. 610-11), the destruction of the Upper Lias is complete, the Upper \(Trigonia\) Grit resting on the \(Striatum\) Clay.

The most complete deposit of the Capricornum and Striatum Clays is at Timsbury Sleight, where they are 120 feet thick. East of this, at Dunkerton, they are reduced to 50 feet, while at Forscote they have suffered reduction to 20 feet, and at Huish to 8 feet. It is suggested that the denudation which removed the Middle Lias also affected the underlying Charmouthian clays, and that, even where these are thickest, they are not necessarily complete. Later, denudation affected the Upper Lias, resulting in its partial removal in the north-eastern area, and its complete destruction, along with part of the underlying clays, in the area around Radstock.

Mr. S. S. Buckman has kindly identified all the Upper Lias ammonites mentioned in this section.

IV. GENERAL DISCUSSION OF THE STRUCTURE AND RELATIONS OF THE LIAS OF THE RADSTOCK DISTRICT.

It will probably be most convenient to summarize here our interpretation of the relations of the Lias, and of the intra-Liassic movements which gave rise to them, and afterwards to indicate in greater detail the reasons for some of these conclusions, especially concerning the deposition of the Lower Lias, where the information is more complete.

Summary of the History of the Area during the Lias.

(1) Deposition of the Hettangian during a period of fairly steady and uniform subsidence.

(2) Period of uplift, accompanied by gentle plication producing

east-and-west folds; denudation of anticlinal areas.

(3) Deposition renewed during the hemera of sauzeani (Bucklandi and Spiriferina Beds). Deposition continued slowly, perhaps intermittently, during the formation of the Turneri Clay over the whole area (fig. 10 a, p. 628).

(4) A period of uplift, greater in the south than the north, and

perhaps least near Dunkerton, led to the removal of much of this sediment, especially in the south.

(5) Deposition of the Obtusum Nodule-Bed, a thin remanié

bed, almost continuously over the whole area.

(6) Deposition of the Raricostatum Clay over the whole area; renewed uplift, particularly in the south and west, led to the removal of much of this clay, and in some places in the south the underlying deposits were also disturbed (fig. 10 b, p. 628).

(7) Deposition of the Armatum Bed in the south, the sediment of this deposit burying the disinterred Echioceras fauna left by the removal of the upper part of the Raricostatum Clay. In the north of the area no deposits accumulated during this time, and the disinterred Echiocerates were not finally buried there until much later.

(8) Deposition of the Jamesoni Limestone fairly uniformly over the whole area; but deposition was still slow, and accompanied

by penecontemporaneous erosion (fig. 10 c, p. 628).

(9) Deposition became more rapid with the commencement of the Striatum Clays, and conditions were for some time fairly normal as compared with those of the Charmouthian elsewhere. It is not unlikely that the Middle Lias (Domerian) was also deposited in the area during a continuance of similar conditions; but, as no Middle Lias is now to be seen in the district, this can be no more than a suggestion.

The succeeding events are not so readily traced, as exposures are not sufficiently frequent to reveal the complete history, but the

following suggestions may be made:-

(10) A period of denudation occurred before the deposition of any part of the Upper Lias; this denudation probably removed whatever Middle Lias had been deposited, together with varying amounts of the *Capricornum* and *Striatum* Clays.

(11) Thin deposits, varying in development from place to place, represent the Upper Lias; the deposits are much disturbed, and were evidently laid down under conditions similar to those which

marked the deposition of the Lower Lias.

(12) Further denudation before the commencement of deposition of the Inferior Oolite resulted in the removal of all the Upper Lias from some areas, a fact which probably indicates the occurrence of further differential movements at that time.

More detailed Account of the Intra-Liassic Movements and the History of Deposition.

(1) Deposition of Hettangian.

(a) White Lias.—The conditions were fairly uniform over the whole area, subsidence keeping pace with deposition, and the White Lias is as thick as is usual in areas on the south, and much thicker than in the north of the Radstock district.

(b) Planorbis Zone.—Fairly uniform over the area, but there were slight movements leading to some differences in the thickness.

of the deposits in different places.

(c) Angulata Zone.—The lower part only of the Angulata Zone was deposited in the district; the conditions probably were similar to those under which the Planorbis Zone was deposited, but continued movements gave rise to still greater differences in thickness.

(2) The Sinemurian Denudation.

No deposits representing the upper Angulata Zone or the lowest part of the Bucklandi Zone are yet known in the district. Their absence is almost certainly due to non-deposition, although some may have been removed by penecontemporaneous erosion. During the time represented elsewhere by these deposits the movements which were first manifested during the deposition of the Planorbis Zone became more notable, leading to the formation of east-andwest anticlines and synclines, with a slight eastward pitch. The synclines developed in general where subsidence had allowed the accumulation of the greatest thickness of the Planorbis and Angulata Zones. The folds were probably sharper in the south near Radstock than farther north.

Denudation was naturally most active in the anticlinal regions, such as those south of Radstock and south of Paulton, where the White Lias was re-exposed, but in the synclinal areas the denudation was very slight, and did little more than emphasize the penecontemporaneous erosion that almost kept pace with the deposition of these zones. The movement was sufficient to prevent the accumulation of sediment, but the succeeding deposits rest without marked discordance on the eroded surface. The junction of the Lower Angulata Zone with the Upper Bucklandi Zone in several exposures occurs in the middle of a single bed of limestone, and no break can be detected.

The precise date of the recommencement of deposition is difficult to determine; as we have already noted (p. 601), the remanié bed (the Spiriferina Bed) that constitutes the next oldest deposit in some areas (for example, Clandown, No. 1) contains ammonites of several hemeræ, commencing perhaps with that of Coroniceras. It probably follows, therefore, that deposits of that date were laid down in that area or in a neighbouring area, but that there was such a paucity of sediment, and the waters were shallowed to such an extent, that the finer material was carried away. During several hemeræ in that neighbourhood deposition was interrupted in this way, and the fossilized but disinterred ammonites of various dates were not finally buried until the hemera of Euagassiceras. areas other than near Clandown, even this partial commencement of deposition did not occur until later; in many exposures the Spiriferina Bed includes phosphatized specimens of Paracoroniceras gmuendense and its allies, while in several others Agassiceras spp. occur. In the Timsbury quarries, however, no ammonites earlier than Eugassiceras are known, and it must be assumed that deposition did not commence there until the time of that genus.

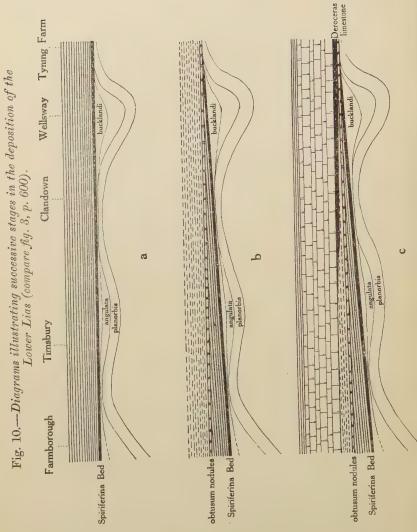
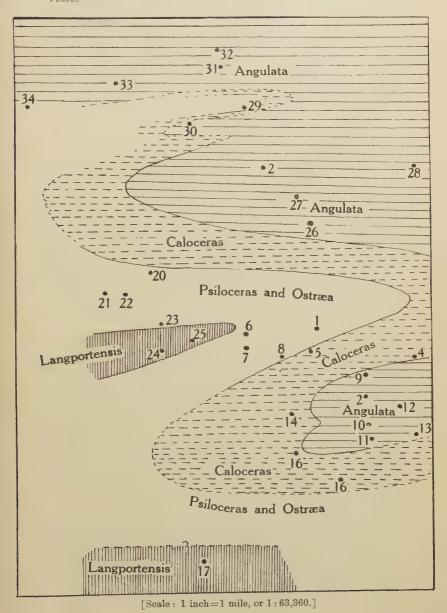


Fig. 11.—Map illustrating the denuded pre-sauzeanum folds, and showing approximately the age of the deposits upon which the Bucklandi Bed rests.



(3) Deposition of the Bucklandi Bed, Spiriferina Bed, and Turneri Clay.

The hemera of Euagassiceras marked a slight but distinct and fairly uniform subsidence, and beds of Euagassiceras date are found in nearly all exposures (except when they have been removed by subsequent denudation). In these deposits were enclosed the fossilized, often phosphatized, ammonites and other fossils of earlier dates, with underived forms contemporaneous with Euagassiceras. Although conditions were relatively stable during this time, they were not quite so, and slight movements accompanying the slow deposition probably account for the fact that many specimens of Euagassiceras have apparently been derived; even the Bucklandi Bed at Timsbury, the ammonites of which are all presumably post-gmuendense, probably contains fossils of diverse ages. This is not surprising, for it is a condensed representative of much thicker deposits elsewhere.

But, with the commencement of the deposition of the *Turneri* Clay, it is probable that accumulation became much more rapid; unburied fossils lying on the sea-floor were buried to form the *Spiriferina* Bed. Deposition continued more rapidly for some time while the *Turneri* Clay was laid down, but it was apparently interrupted by movements, and recently fossilized or partly fossilized shells were washed out of their deposit, often eroded and re-interred; the fossils are generally incomplete body-chambers, and the deposits do not constitute a full record of the time taken

in deposition.

(4) Pre-Obtusum Denudation.

Before the deposition of the *Obtusum* Nodules another important period of denudation occurred; in the south of the area, around Radstock, practically the whole of the *Turneri* Clays were removed, and it is probable that this period of erosion followed an uplift which was greater in the south near Radstock than in the north near Timsbury and Camerton, where a greater thickness of these clays has been preserved. Higher horizons in the clays, with several types of *Arnioceras* that are unknown farther south, are found at Timsbury. It should be noted that these pre-obtusum movements were different in character from the movements which occurred during *Euagassiceras* times; they were probably simpler, and corresponded with a general uplift along the Mendip axis.

(5) Deposition of the Obtusum Nodules.

The Obtusum Nodules are remarkably constant in characters over almost the whole district; wherever they are absent it is likely that they have been removed by subsequent denudation. It appears probable, therefore, that the nodules represent a fairly uniform deposit over a large area; they probably represent a remanié bed, and contain ammonites of different dates, but the

fossils are not so evidently derived as those of the Spiriferina Bed and the Armatum Bed.

The *Obtusum* Bed at Timsbury is thicker than in most exposures; the upper nodule-bed at Timsbury, however, appears to be identical with the *Obtusum* Nodules of other localities, and it is therefore to be inferred that earlier deposits of *obtusi* date are preserved at Timsbury. Possibly such deposits were removed elsewhere before the formation of the Nodule-Bed as a remanié deposit.

The sequence at Timsbury appears to be the most complete,

both in the Turneri Clay and in the Obtusum Beds.

(6) Deposition of the Raricostatum Clay.

No deposits indicating the *Oxynotum* Zone are to be seen in the Radstock area, and probably there was a pause in deposition previous to the commencement of the deposit of the *Raricostatum* Clay. The lowest horizon with Echiocerates is also unrepresented.

The conditions under which the Raricostatum Clay was laid down probably resembled those of the Turneri Clay; on the whole, the deposits are of similar character, and the fossils which they contain almost all show some indication of erosion. It is probable that during the time when this clay was accumulating the area was unstable, and the fossils were exhumed and re-interred repeatedly, so that the true sequence is rarely shown. Renewed uplift (compare 4 above) in the south led to the removal of much of this clay, especially in the area south of Radstock (see fig. 10b, p. 628), and the succession was rendered still less complete.

At least nine Echioceras faunas are known from the Radstock district; the details of these are given later (p. 645), but the chief faunas may be known in order of date—zieteni, raricostatoides, macdonnellii, aplanatum. Representatives of the first are found in the Raricostatum Clay. At Timsbury, where the clay is best seen, the zieteni fauna is seen below the macdonnellii fauna, while in the areas on the south the macdonnellii fauna is not always present, and presumably was removed before the deposition of the Armatum Bed. At Vobster deposition commenced after raricostatoides time.

Where the Armatum Bed was deposited it includes derived Echiocerates of the raricostatoides type; especially in the quarries around Radstock and farther south, these specimens in the Armatum Bed are well preserved, far better preserved than the specimens which are in situ in the Raricostatum Clay at Timsbury. It may perhaps be inferred that the Raricostatum-Clay deposits in the Radstock neighbourhood were less affected by contemporaneous movements than those near Timsbury.

¹ Several derived fragments of Oxynoticeras spp. have recently been collected from the Armatum Bed at Rockhill (5, p. 607), and may indicate that some part of the 'Oxynotum Zone' was deposited in the area.

(7) Deposition of the Armatum Bed.

The earliest deposits of the Armatum Bed buried the nodules with derived Echiocerates that had been exposed in the post-macdonnellii denudation. In this bed are also included well-preserved specimens of Echioceratide of the aplanatum type; from their preservation and from their distribution it appears probable that the deposition of this bed had commenced in the time of aplanatum.

Also preserved in this bed, along with numerous Derocerates, are many large oxycone Arietids, chiefly of the genera Victoriceras and Tutchericeras. Some specimens at least of Victoriceras appear to have been derived; they are in blocks of limestone darker than the Armatum Bed, but no trace of such a limestone has been

seen in the area investigated.

The Armatum Bed is persistent and of very constant character, from the south of Radstock as far north as Bowldish and Paulton; it is quite unrepresented at Timsbury, and probably in the country north of Timsbury at least as far as Dundry. It follows, therefore, that a fairly general uplift in the north led to the denudation, or prevented accumulation, of the deposits from aplanatum to leckenbyi.

(8) Deposition of the Jamesoni and Valdani Limestones.

The deposits of the Jamesoni Limestone succeed the Armatum Bed with no apparent break; in the north of the area the basal deposits of the Jamesoni Limestone include derived Echiocerates. The succession of ammonites in the Jamesoni Limestone is fairly complete for so thin a group, and there is comparatively little evidence of erosion or non-deposition during the time represented by these deposits. The deposit is uniform over a wide area, from Vobster in the south to Paulton and Timsbury in the north, but farther north the rubbly ironshot limestone passes into the more usual Charmouthian clays.

(9) Deposition of Striatum Clays, etc.

In post-valdani times deposition became more rapid, perhaps as a result of a more general subsidence of the whole region. The deposits of this period are of more normal character.

General Relations.

It is probably clear that the peculiar characters of the Lias at Radstock result from its relation to the Mendip axis a few miles away to the south. It has frequently been demonstrated that movements along this axis occurred intermittently throughout Jurassic times. These movements during the deposition of the Lias were probably intense enough to prevent the accumulation of much sediment in the area of the Mendips. It is not certain

that land existed in the Mendip region continuously through Liassic times; but it is apparent from the sections at Vobster and at Vallis Vale, near Frome, that there was no effective subsidence of the pre-Liassic floor throughout the time represented by the

Hettangian and Sinemurian deposits.

It must be noted that the Liassic rocks of Radstock are not to be regarded as littoral deposits. They are different in lithological and in faunal characters from the littoral rocks of other parts of Somerset and of Glamorgan, where deposition near a shore-line accompanied steady subsidence. Littoral deposits of Sutton-Stone aspect are, of course, found against the Carboniferous Limestone in parts of the Mendips; but these littoral deposits represent only the lowest zones of the Lias, and presumably most of the islands of Carboniferous Limestone which were not submerged in the Trias did not long escape burial in the Lias. Those areas of Carboniferous Limestone which were later re-exposed by further elevation did not provide enough material for the formation of typical littoral deposits.

We have shown that the peculiar variations in thickness of certain divisions of the Lower Lias near Radstock are to be explained by the intra-Liassic folding and penecontemporaneous erosion. It is important to notice that the axes of the folds, and of all other intra-Liassic movements of which evidence has been obtained, were parallel to the Mendip axis, and were probably

related to movements along that axis.

It is not necessary to emphasize the similarity of the intra-Liassic folding of this district and the Bajocian folding demonstrated by Mr. S. S. Buckman in the Cotteswolds.\(^1\) In each case gentle movements lasting for a considerable time, and leading to greater accumulation of sediment in some areas than in others, were followed by more pronounced movements along the same lines; after a period of erosion a uniform bed (the Spiriferina Bed in one case, the Upper Trigonia Grit in the other) was laid down on eroded deposits of various dates. The evidence of similar movements during the deposition of the Coal Measures in South Wales, recently described by Mr. R. Davies & Prof. A. H. Cox, is of some interest in this connexion.\(^2\)

While there appears to be little doubt that these movements during the deposition of the Radstock Lias were related to movements along the Mendip axis, it is somewhat surprising to find that the Liassic rocks south of the Mendips apparently do not show any of the characters that are so remarkable at Radstock. The Lias south of the Mendips (for example, near Shepton Mallet and Street) includes thick deposits of the lowest zones, with no prominent indications of penecontemporaneous erosion. It is

¹ See, for instance, 'The Bajocian of the North Cotteswolds' Q. J. G. S. vol. lvii (1901) p. 147.

^{2 &#}x27;On Thickness Variations in the Lower Coal Measures of East Glamorganshire, &c.' Proc. S. Wales Inst. Eng. vol. xxxviii (1922) p. 41.

possible that north of the Mendips the interaction of other movements, namely those which gave rise to north-and-south folds in that area, may have been partly responsible for the peculiar conditions. On the other hand, the Middle Lias is found near Glastonbury, not far south of the axis of the Mendips, and this indicates that the deposits are much more complete in that region; further, the occurrence of a series of outliers of Middle Lias westwards from Glastonbury to Brent Knoll possibly indicates a fairly considerable development of Lias along this tract. It is not, therefore, unlikely that the region immediately south of the Mendip area underwent comparatively steady subsidence, notwithstanding the contemporary movements along the axis to the north. It may be noted that in Glamorgan the Lower Lias is also thickly developed in the area south of the Cardiff-Cowbridge anticline, which may perhaps be regarded as the western replacement of the Mendip axis. An area of thick Liassic deposits may therefore be supposed to have existed between the Mendips and the Quantock Hills, and westwards along the Bristol Channel. This accords in general with the distribution of the divisions of the Rhætic determined by Mr. L. Richardson.²

Mr. Buckman, some years ago, called attention to the fact that at Radstock an unusual proportion of large ammonites 3 occurs; almost every family of ammonites in the Lower Lias is represented there by species that appear to be bigger than the normal members of that family. To some extent, as Mr. Buckman suggests, this may be explained by the absence, or the non-discovery, of the corresponding faunas in other areas, but we believe that it may, in part at least, be due to the favourable conditions of existence, perhaps to an abundance of food in the shallow waters (or near the shores) in the Mendip region of the Liassic sea.

V. NOTE ON THE ORIGIN OF NODULAR LIMESTONES.

Attention has recently been called to the problem of the origin of nodular limestones, by Dr. W. D. Lang, Dr. W. A. Richardson, and others.⁴ Briefly, it may be recalled that these writers have suggested that the limestones developed subsequently to the deposition of a series of calcareous clays. Dr. Richardson believes that they were rhythmically precipitated during the desiccation of the deposits, this desiccation being possibly accompanied by elevation. In his investigation of the succession of the Lower Lias of Dorset, he found evidence of only one such rhythm, and

² The Rhætic & Contiguous Deposits of Glamorganshire Q. J. G. S. vol. lxi (1905) p. 385.

³ Q. J. G. S. vol. lxxiii (1917-18) p. 315.

¹ A. E. Trueman, 'The Liassic Rocks of Glamorgan' Proc. Geol. Assoc. vol. xxxiii (1922) p. 245.

⁴ W. D. Lang, 'The Geology of the Charmouth Cliffs, &c.' Proc. Geol. Assoc. vol. xxv (1914) p. 297; W. A. Richardson, 'Shales-with-Beef: pt. iii' Q. J. G. S. vol. lxxix (1923) p. 95; A. E. Trueman, op. jam cit. 1922, p. 274.

therefore, if his hypothesis is correct, the precipitation of calcium carbonate took place not earlier than the date of the Middle Lias. In Glamorgan one of us showed that at least two rhythms were present, and a first period of precipitation must presumably have occurred there before the commencement of deposition of the Bucklandi Zone.

The Radstock succession affords interesting new evidence: it may be noted that the deposits of the Planorbis and Angulata Zones are shales with nodular limestones, which, when fully developed, as at Wellsway and Farmborough, are of the same general character as the Blue Lias of Dorset and Glamorgan. But we have shown that these deposits were folded and largely denuded from most areas near Radstock before the deposition of the Spiriferina Bed, and it therefore follows that, if the nodules originated as secondary precipitates, they cannot have been formed later than the time of uplift that preceded their denudation.

VI. FAUNAL NOTES.

In the following pages are given lists of the more important species that have been identified at Radstock. In the case of the ammonites more detail has necessarily to be supplied than in other groups: for, despite the large number of Radstock ammonites figured by Mr. S. S. Buckman in recent years (1910-1925), a great many species are yet undescribed. New specific names or additional descriptions are only introduced here where they appear to be necessary for the identification of a horizon, or for the definition of an important fauna.

Ammonites.

Family CALOCERATIDÆ.

Psiloceras planorbis (Sowerby). Rare; exposure 6, pp. 608-609.

Psiloceras sampsoni (Portlock).

Psiloceras plicatulum (Quenstedt).

Psiloceras johnstoni (Reynès, 'Monogr.' 1879, pl. i, fig. 5).

Caloceras johnstoni (Sowerby).

Caloceras pirondii (Reynès).

Caloceras intermedium (Portlock).

Caloceras convolutum (J. Simpson) 'Type Ammonites' 1910, no. 18.

Alsatites liasicus (A. d'Orbigny): exposure 32, p. 620.

Alsatites aff. laqueolus (Reynès non Schlotheim).

Schlotheimia cf. depressa (Quenstedt).

Schlotheimia acuticosta (Strickland).

Schlotheimia gallica S. Buckman.

Schlotheimia prometheus (Reynès).

Schlotheimia stricklandi S. Buckman.

Schlotheimia (?) colubrata (Zieten).

Franziceras rudum S. Buckman: exposure 10, p. 610.

¹ Details of exposures are only given in those cases where the distribution is peculiar or limited.

Family ARIETIDÆ.

Coroniceras ef. hungaricum (Hauer). Stout forms, derived, in the Spiriferina Bed at exposure 5, p. 607.

Coroniceras sp., exposure 1, pp. 600-601.

Megarietites meridionalis (Reynès), exposures 1 & 5.

Megarietites multicostatum (Reynès).

Agassiceras (Ætomoceras) scipionis (Reynès). Stouter forms than A. scipionianum (A. d'Orbigny); the bulk of the Radstock specimens are smooth (or nearly so) by the diameter of 200 mm., and are more involute than Reynès's species.

Agassiceras cf. nudaries (Schmidt, Palæontographica, 1914, vol. lxi, text-

fig. 4).

Agassiceras nodulatum S. Buckman.

Agassiceras aff. colesi (J. Buckman). Paracoroniceras gmuendense (Oppel).

Paracoroniceras trigonatum (Hyatt). ? Eucoroniceras hebe (Reynes, 'Monogr.' 1879, pl. xxv, figs. 5-10 only).

Euagassiceras (Agassiceras) sauzeanum (A. d'Orbigny).

Euagassiceras spinaries (Quenstedt).

Euagassiceras subtaurum (Reynès, 'Monogr.' 1879, pl. xix, figs. 12-15).

Euagassiceras halecis (J. Buckman).

Euagassiceras striaries (Quenstedt).

Epammonites isis (Reynès): Spiriferina Bed, exposures 1, 6, 24.

Epammonites latesulcatus (Schmidt), exposure 6, pp. 608-609.

Epammonites insigne (Fucini).

Epammonites parthenope (Reynès), exposure 1, pp. 600-601.

Arietites turneri (Sowerby).

Arietites turgescens S. Buckman.

Asteroceras cf. obtusum (Sowerby). Asteroceras stellare (Sowerby).

Asteroceras cf. smithi (Sowerby). Asteroceras ef. margaritati Parona.

Genus Arnioceras.

This genus is one of the easiest to identify, but the species of Arnioceras are most difficult to separate, even when the material is good. Yet separation is essential, since the genus has a comparatively long range. Dr. L. F. Spath has made a study of the Arnioceras material from Dorset collected by Dr. W. D. Lang.1 By the kindness of Dr. Lang and the authorities of the British Museum (Natural History) we have been permitted to examine typical Dorset specimens; but we are not, in many cases, able to identify the Radstock specimens. It will, therefore, be necessary to give fuller notes on this group, since Arniocerates are particularly abundant in the Radstock Lias.

Arnioceras hartmanni (Oppel).

Typical specimens, closely comparable with A. kridion,2 are represented by isolated body-chambers in the Turneri Clay in many exposures.

W. D. Lang & L. F. Spath, 'Shales-with-"Beef": pts. i & ii' Q. J. G. S. vol. lxxix (1923) p. 47. ² A. d'Orbigny, 'Terrains jurassiques: I—Céphalopodes' pl. xxxi, figs. 1 & 2.

Specimens with a flatter venter, more closely resembling A. hartmanni Hyatt, are found in the Obtusum Nodules in several places. These frequently attain the diameter of 100 mm. The inner whorls are smooth up to a diameter of about 15 mm. and the smooth whorls appear to have broad flat sides, a useful distinction from some of the earlier species.

Arnioceras crassicosta sp. nov. (Pl. XXXIX, figs. 1 a–1 b & text-fig. 12 d.)

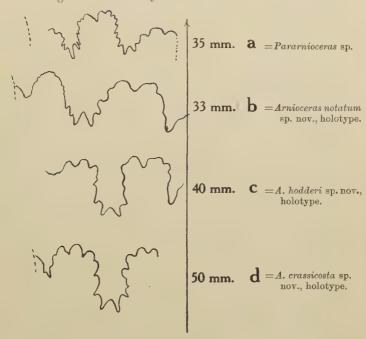
Compare A. mendax var. rariplicata Fucini (1902, pl. xviii, fig. 9).

A large stout form, represented by fragments only, from the Obtusum Bed at Timsbury.

Approximate dimensions.

Diameter. Whorl Height. Whorl Thickness. Umbilicus.
110 mm. 22 per cent. 18 (22) per cent. 63 per cent.

Fig. 12.—Sutures of Arnioceras and Pararnioceras.



This species has a thicker but more slender whorl than A. bodleyi and A. hartmanni, It is ornamented by massive ribs, slightly curved, approximately radial, which swing sharply forwards

¹ Genesis of the Arietidæ 1889, pl. ii, figs. 17 & 18 only.

at the external margin, and tend to form a ridge bounding the

sulci. The suture has a wide IL.1

A. crassicosta is perhaps related to the specimens designated by Dr. L. F. Spath Arnioceras cf. geometricum (Phillips) var. hartmanni (Oppel)²; but the ribs are stronger, more widely spaced, and less curved.

The holotype is from the hard band at the base of the *Obtusum* Bed at Timsbury (exposure 2, pp. 604-605): British Museum

(Natural History) no. C 26789, ex A. E. Trueman Coll.

Arnioceras cf. bodleyi (J. Buckman).

Refigured by S. S. Buckman, 'Palæontologia Universalis' 1904, no. 36.

Specimens very near the Cheltenham A. bodleyi are found in the clay immediately above the Spiriferina Bed; for example, in exposures 2 (pp. 604–605) and 10 (p. 610).

Arnioceras cf. speciosum Fucini (Spath).

Specimens almost identical with those named by Dr. Spath from the *Pararnioceras-alcinoe* Bed of Dorset (W. D. Lang Coll. 2563) occur in the *Turneri* Clay at Newtown Quarry, Paulton (21, p. 615).

Arnioceras fortunatum S. Buckman (op. cit. 1917, p. 301).

The holotype of Buckman's species is from Paulton, but the horizon was unknown. Exactly similar specimens have been collected from the Bucklandi Bed at Timsbury and Paulton. The inner whorls of this species are flat and fairly wide; sharply reclined ribs appear at a diameter of about 20 mm., and are at first confined to the external portion of the lateral area. This species is probably related to the last, as suggested by Fucini, but they are quite distinct; the costa are much more widely spaced than in A. speciosum.

Arnioceras cf. falcaries Hyatt ('Genesis of the Arietidæ' 1889, pl. ii, fig. 25).

Arnioceras notatum sp. nov. (Pl. XXXIX, figs. 2 a & 2 b.)

A slender raricostate Arnioceras.

Approximate dimensions.

Diameter. Whorl Height. Whorl Thickness. Umbilicus. 55 mm. 20 per cent. 18 per cent. 62 per cent.

The whorls are smooth and rather wide until the diameter of 23 mm., when rather widely-spaced folds appear on the external part of the side, as in A. fortunatum. Only 20 ribs are present

¹ The elements of the suture-line are indicated by the usual symbols: that is, EL, external lobe; ES, external saddle: IL, first lateral lobe; IS, first lateral saddle.

^{*}

Q. J. G. S. vol. lxxix (1923) p. 70.

on the succeeding whorl, and the ribs keep this wide spacing throughout. They are straight, with a small tubercle at the external angle, and very slightly reclined. Periphery fairly wide, sulcate. This species has some resemblance to A. fortunatum, but is much more slender and the costæ are much later in appearing. The suture (fig. 12 b, p. 637) also resembles that of A. fortunatum (S. S. Buckman, 1917, pl. xxxi, fig. 4 b).

Holotype: A specimen from the Bucklandi Bed (Euagassi-

ceras) at Rockhill (no. 5, p. 607); J. W. T. Coll.

Arnioceras hodderi sp. nov. (Pl. XXXVIII, figs. 1 a-1 c.)

Compare Arnioceras insolitum var. longispiratum Fucini.1

Dimensions.

	Diameter.	Whorl Height.	Whorl Thickness.	Umbilicus.
(a)	76 mm.	20 per cent.	17 (20) per cent.	62 per cent.
(b)	53 mm.	22 per cent.	19 (22) per cent.	56 per cent.
		(a) the holotype; (a)	b) a smaller topotype.	

A rather slender Arniocerate with nearly straight ribs, radial or slightly reclined. The whorl is not so broad and the sides are not so flat as in A. bodleyi, which the form here described resembles to some extent. The periphery in the type is broad, with a fairly prominent keel and feeble sulci; but the costa rarely (if ever) fuse to form a ridge along the edge of the periphery.

The innermost whorls are much slenderer (that is, the shell is more polygyral) than those of A. bodleyi and A. fortunatum, and they resemble those of A. semicostatum, except that costation commences earlier. In the holotype striæ are present at a diameter of 8 mm., and low subcostæ at about 16 mm. In a smaller topotype costation does not commence until a diameter of 17 mm. The species somewhat superficially resembles a form figured by Fucini, mentioned above; but it is thicker, and has inner whorls of different character.

The suture-pattern (fig. 12 c, p. 637) is not unlike that of A. bodleyi, but in the latter IS is much higher than ES, and the whole suture seems to be inclined; this feature appears to be variable, however, and is shown in some young specimens of A. hodderi.

Holotype: A specimen in a dark matrix, from the Agassiceras Bed (possibly derived) at Hodder's Quarry, Timsbury (no. 2, pp. 604-605); J. W. T. Coll.

ARNIOCERAS cf. SEMICOSTATUM Young & Bird.

Small specimens; costate earlier than the type of A. semicostatum, at a diameter of 16 mm. Probably they are comparable with A. cf. semicostatum Spath (W. D. Lang Coll. 2759). Obtusum Nodules, 10.

¹ A. Fucini, 'Palæontologia italica' vol. viii (1902) pl. xix (xxii), fig. 5.
Q. J. G. S. No. 324.
2 U

Arnioceras ef. flavum S. Buckman (op. cit. 1917, p. 299).

This name was proposed for a small *Arnioceras* from an unknown horizon at Lyme Regis. A specimen from the *Obtusum* Nodules at Phyllis Hill (J. W. T. Coll.) is similar, but thinner and more slender.

Dimensions.

Diameter. Whorl Height. Whorl Thickness. Umbilicus.

A. flavum (type). 25 mm. 27 per cent. 20 per cent. 51 per cent.

Our specimen ... 27.5 mm. 24 per cent. 15 per cent. 52 per cent.

The specimen has a distinct carina, and faint reclined pilæ on the last whorl.

ARNIOCERAS cf. NIGRUM Blake.

Thinner than Blake's species, quite smooth, and with an angular periphery. Probably belongs to the same series as A. cf. semicostatum (above). From Phyllis Hill (J. W. T. Coll.).

Arnioceras cf. spirale Fucini (1902, pl. xix, fig. 6 only). Exposure 2 (p. 605), Bucklandi Bed.

Arnioceras cf. Geometricum (Oppel); a large specimen from exposure 1, referred to by Buckman (op. cit. 1917, p. 301).

Genus PARARNIOCERAS.

A number of derived specimens from the Spiriferina Bed and the Bucklandi Bed, at exposures 1, 2, 5, & 15, are somewhat doubtfully referred to the genus Pararnioceras of Spath. One specimen, not showing the inner whorls, is identified with P. alcinoe (Reynes). The other specimens are more finely ribbed, and are referred to P. cf. isis (Reynès, Monogr. pl. xvii, fig. 6 only) and P. cf. vercingetorix (Reynès, pl. xx, fig. 8), although several other species are perhaps represented. These specimens are smaller than the specimens commonly found in Dorset, and in some cases show the innermost whorls, which are unknown in the Dorset specimens. One specimen is figured in Pl. XXXVIII, figs. 2 a-2 c. The inner part of the umbilicus is deep, and the whorls expand rapidly; from a very early diameter they are ornamented by very stout costæ, about six or eight to a whorl, most prominent near the external margin, where they often appear as rounded tubercles. Similar forms from Cheltenham have recently been described by one of us as Pararnioceras.2

If these forms are correctly referred to *Pararnioceras*, it follows that Dr. Spath is justified in separating them from other genera,

¹ L. F. Spath, Abstr. Proc. Geol. Soc. No. 1079, January 13th, 1922, p. 30; and 'Ammonites of the Shales-with-Beef' Q. J. G. S. vol. lxxix (1923) p. 73. j ² A. E. Trueman, 'Notes on the Ammonites' [Appendix to a paper by L. Richardson & R. C. S. Walters], Proc. Cottesw. Nat. F.C. vol. xxi (1922) p. 172.

for the inner whorls are very different in character from those of genera allied to *Arnioceras*. Yet the outer whorls of some specimens are scarcely distinguishable from some species of *Epammonites*. The appearance of the inner whorls supports Dr. Spath's suggestion that the genus *Pararnioceras* originated

in Euagassiceras.

The suture-lines of our specimens (fig. 12 a, p. 637) agree fairly closely with those of P. alcinoe (Reynès, pl. xxiii, fig. 11), but some species of Epammonites show sutures of approximately the same pattern, while other species referred to this genus by Spath have sutures of a very different character. It appears probable, therefore, that, while it is certain that these recently-proposed genera are needed for the adequate discussion of the Arietidæ, considerable further studies of ontogeny and sutures are necessary before the genera can be satisfactorily used.

Arietidan Oxycones.

The Radstock Lias yields many Arietidan oxycones, often of large size. These are most abundant in the Armatum Bed; but even these are probably of various dates, while other genera are found at one or more horizons in the Jamesoni Limestone. It may be assumed that these oxycones represent 'homeomorphous terminals of different lineages' (Buckman, op. cit. 1917. p. 288), related to the Arietidæ, which migrated into the British area at intervals during the Oxynoticeratan and succeeding ages. The diverse origins of these genera are indicated by the different sutural characters which they present; the plan of the suture is very constant in each genus, and may ultimately make it possible to link up each oxycone with the forms from which it may have been derived. Thus the suture of Guibaliceras resembles fairly closely that of Coroniceras and associated genera, and it is typically Arietidan in the shallow IL, while Victoriceras is easily recognized by the deep notch on the external side of the ES.

TUTCHERICERAS PERFOLIATUM S. Buckman.

Holotype from Radstock Grove (10, p. 610); also from 1 (p. 601), Armatum Bed.

This species is most easily recognized by the very flat periphery

in casts.

? Guibaliceras guibalianum (A. d'Orbigny).

A cast, showing no ornamentation, from 6 inches above the base of the *Armatum* Bed at Westfield (15, p. 611), should perhaps be referred to this species. The suture agrees closely with that figured by Buckman (op. cit. 1917, fig. 14, p. 295). It may be noted, however, that a similar suture is shown in *Ammonites buvigneri* Wright, although this can scarcely be a species of *Guibaliceras*.

2 U 2

¹ T. Wright, 'British Lias Ammonites' Monogr. Palæont. Soc. 1878, pl. lxxvi, figs. 1-3.

RADSTOCKICERAS ef. BUVIGNERI (A. d'Orbigny, non Wright and others).

From the Jamesoni Limestone, Tyning Colliery (4, p. 607).

This differs from R. complicatum in having a thinner shell with smaller umbilicus. The whole shape is also different, the thickest part being farther from the umbilical border than in R. complicatum.

RADSTOCKICERAS COMPLICATUM S. Buckman: Jamesoni Limestone, exposure 1, p. 601.

GLEVICERAS aff. GLEVENSE S. Buckman. (Fig. 13.)

Compare Ammonites guibali Reynès (Monogr. pl. xlvi, fig. 13 only).

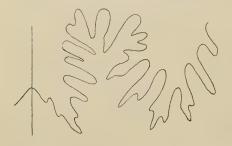
Dimensions.

Diameter. Whorl Height. Whorl Thickness. Umbilicus. 164 mm. 51 per cent. 24 per cent. 16 per cent.

Armatum Bed, exposure 10, p. 610.

A cast, about half a whorl merely, showing part of the shell near

Fig. 13.—Outline of the sutures of Gleviceras aff. glevense S. Buckman.



the keel only; this part has close subcoste, which apparently become fainter farther from the keel. The venter on the cast is convexifastigate. Keel apparently obsolescent.

Whorl thick, thickest at a third of the distance from umbilical border. A whorl earlier the keel was sharper, but not a knife-edge.

The sutures most closely resemble those

of Gleviceras glevense S. Buckman (op. cit. 1917, fig. 5, p. 294) in having wide ES, cut by a deep notch nearest the internal side, IL distinctly deeper than EL, with four lobules arranged radially (fig. 13).

This specimen probably represents a species more advanced than

G. glevense. [A. E. T. Coll.]

GLEVICERAS SP.

A complete specimen from exposure 5, p. 607.

VICTORICERAS VICTORIS (Dumortier). Common in the Armatum Bed in many exposures, especially 1, 4, 5, 10, 11, and 15.

VICTORICERAS IRIDESCENS Sp. nov. (Fig. 14.)

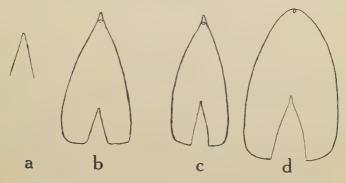
A large smooth *Victoriceras*, representing a later stage than *V. victoris*.

Dimensions.

Diamet	er. Whorl Height.	Whorl Thickness.	Umbilicus.
Holotype 245 mm	a. 49 per cent.	28 per cent.	22 per cent.
$\left.\begin{array}{c} A \text{ large } V.\\ victoris \end{array}\right\} 215 \text{ mm}$. 48 per cent.	23 per cent.	18 per cent.

The broken shell in the holotype shows the whorl shape at successive stages, illustrated in fig. 14. It will be noted that the young shell has an almost knife-edge periphery (oxygastric). In the last whorl, however, it is stouter than in V. victoris, and the periphery on the cast is well rounded.

Fig. 14.—Changes in the shape of the whorl in Victoriceras iridescens sp. nov., to different scales.



[a=at 25 mm.; b=at 80 mm.; c=at 120 mm.; d=at 250 mm.]

Some trace of ornamentation is present on the inner whorls, but its character cannot be determined. The suture is of the same pattern as that of V. victoris, but is more complicated. \Rightarrow Holotype: A specimen from the Armatum Bed at Westfield

(p. 611), apparently derived; A. E. T. Coll.

Phylloxynotites phyllinus S. Buckman. Jamesoni Limestone.

Phylloxynotites simillimum (Pia). Exposure 14, Jamesoni Limestone.

Fastigiceras clausum S. Buckman. Exposures 2, 3, & 4; horizon uncertain, probably Jamesoni Limestone.

Metosynoticeras oppeli (Schloenbach). Jamesoni Limestone, exposure 4. Oxynoticeras cf. sæmanni (Dumortier). Derived in the Armatum Bed, exposure 5 (p. 607); rare.

Homoxynoticeras homœum S. Buckman.

Kleistoxynoticeras columellatum S. Buckman.

Oxynoticeras williamsi sp. nov. (Pl. XLI, figs. 3 a-3 c.)

A single fragment collected by Miss D. M. Williams, M.Sc., is perhaps related to O. sæmanni, with which it agrees fairly closely in suture pattern, especially in the regular series of auxiliaries. It differs from that species, however, in the inclination of the auxiliaries.

The thickest part of the whorl is near the umbilicus, and the whorl is, therefore, more trigonal in form than that of O. sæmanni; at an early stage, however, seen where the shell is broken, the whorls are more nearly oval in shape. Periphery angular, cast almost as sharp as the shell.

Dimensions.

	Diameter.	Whorl Height.	Whorl Thickness.	Umbilicus.
	67 mm.	56 per cent.	21 per cent.	?3 per cent.
Holotype	34 mm.	65 per cent.	22 per cent.	
O. sæmanni 1	58 mm.	58 per cent.	17 per cent.	4 per cent.

Holotype: A specimen from the *Armatum* Bed (derived) at Rockhill (exposure 5, p. 607): now in the British Museum (Natural History), no. C 26788.

Family DEROCERATIDÆ.

Xipheroceras cf. capricornoides (Quenstedt). Obtusum Nodules, exposure 24, p. 616.

Xipheroceras planicosta (Sowerby). Obtusum Nodules, fairly common. Xipheroceras dudressieri (A. d'Orbigny). Obtusum Nodules, exposure 2, p. 605. (See Tawney, 1875, p. 184.)

? Microceras cf. subplanicosta (Oppel); a derived specimen from the Armatum Bed, exposure 21, p. 615.

? Microceras cf. vesta (Reynès); a specimen agreeing with Reynès's figure, which is Ammonites planicosta Dumortier, in whorl form and in ribspacing, but differing in having a simpler suture and reclined ribs. From the Armatum Bed (derived), exposure 21.

Deroceras aff. armatum (Sowerby).

Deroceras aff. heberti (Oppel).

Deroceras aff. milleri (Wright), exposure 10, p. 610.

Apoderoceras leckenbyi (Sowerby), common.

Apoderoceras (?) aff. submuticum (Dumortier non Oppel), exposure 10.

Apoderoceras lobulatum S. Buckman, exposure 12, p. 610.

Apoderoceras ferox S. Buckman, exposure 10.

Apoderoceras tardarmatum S. Buckman, exposure 10.

Epideroceras spp.

Phricodoceras lamellosum (A. d'Orbigny), exposures 5 & 10, pp. 607, 610.

Phricodoceras proboscideum (Zieten), exposure 7, p. 609.

Family ECHIOCERATIDÆ.

An account of the ammonites of this family has been prepared by Miss D. M. Williams and one of us (1925), and numerous Radstock species are figured there; a brief reference to the family

¹ E. Dumortier, 'Dépôts jurassiques du Bassin du Rhône, pt. 2 ' 1867, pl. xl, fig. 4.

will, therefore, be sufficient at present. The following species are recorded from the district:-

Echioceras cf. raricostatum (Zieten). Raricostatum Clay, exposure 2. Echioceras zieteni (Quenstedt). Raricostatum Clay, exposures 2, 1.

Echioceras microdiscus (Quenstedt), Raricostatum Clay.

Echioceras raricostatoides Vadasz.

Echioceras crassicostatum Trueman & Williams.

Echioceras inflatum Trueman & Williams.

Echioceras sparsicostatum Trueman & Williams, exposure 10, p. 610.

Echioceras torquatum Trueman & Williams, exposure 10.

Echioceras notatum Trueman & Williams.

Echioceras modicum Trueman & Williams.

Echioceras iridescens Trueman & Williams. Echioceras lepidum Trueman & Williams.

Echioceras lævidomus (Quenstedt).

Echioceras ef. costidomus (Quenstedt).

Pleurechioceras deciduum (Hyatt), exposure 10.

Echioceratoides regulare Trueman & Williams, exposure 10.

Echioceratoides prorsum (S. Buckman).

Echioceratoides viticola (Dumortier).

Echioceratoides favrei (Hug). Upper part of the Raricostatum Clay, exposure 2, p. 605.

Epechiocera's expansum Trueman & Williams, exposure 1, p. 601.

Plesechioceras delicatum (S. Buckman), exposure 21, p. 615.

Plesechioceras comptum Trueman & Williams, exposure 6, p. 609.

Plesechioceras schlumbergeri (Reynès).

Orthechioceras recticostatum Trueman & Williams, exposures 10, 17.

Orthechioceras radiatum Trueman & Williams, exposure 17, p. 613. Orthechioceras cf. subquadratum (S. Buckman), exposure 17.

Euchioceras nobile Trueman & Williams.

Euchioceras angustilobatum Trueman & Williams, exposure 10, p. 610.

Euchioceras rothpletzi (Bose).

Euchioceras cf. bæhmi (Hug).

Euchioceras insigne Trueman & Williams.

Paltechioceras elicitum S. Buckman, exposure 10.

Paltechioceras dignatum Trueman & Williams, exposure 10. Paltechioceras ebriolum Trueman & Williams, exposure 10.

Leptechioceras cf. macdonnellii (Portlock).

Leptechioceras meigeni (Hug), exposure 6, p. 609.

Leptechioceras hugi (S. Buckman).

Leptechioceras subplicatum Trueman & Williams, exposure 1, p. 601.

Leptechioceras planum Trueman & Williams, exposures 1 & 5 only.

Kamptechioceras variabile Trueman & Williams, exposure 10.

Cf. Metechioceras aplanatum (Hyatt).

Vobstericeras flexicostatum Trueman & Williams, exposure 10.

The investigation of the distribution of these faunas in the various quarries leads to the view that they represent not less than nine separate faunas, the sequence of some of which may be as follows :-

- (7) Orthechioceras.
- (6) Euchioceras.
- (5) Leptechioceras macdonnellii.
- (4) Leptechioceras planum.
- (3) Plesechioceras.
- (2) Echioceras raricostatoides.
- (1) Echioceras zieteni.
- (?) Paltechioceras.
- (?) Epechioceras expansum.

It is significant that raricostate Echiocerates are absent at Vobster (18, p. 613), where the earliest fauna represented appears to be *Plesechioceras* and where *Orthechioceras* is well developed. Within the immediate neighbourhood of Radstock, *Paltechioceras* and *Leptechioceras planum* are very restricted in distribution, and represent apparently distinct deposits, which are only preserved in occasional traces.

Family POLYMORPHIDÆ.

Cymbites cf. globosus (Quenstedt, 1849, pl. xv, fig. 8). Valdani Limestone, 20, p. 615.

Cymbites lævigatus (Sowerby). Obtusum Nodules, 2 & 24, pp. 605, 616.

Polymorphites trivialis (Simpson). Polymorphites mixtus (Quenstedt).

Polymorphites lineatus (Quenstedt).

Polymorphites cf. jupiter Trueman (non A. d'Orbigny).

Polymorphites aff. quadratus (Quenstedt).

Polymorphites caprarius (Quenstedt).

PERIPLEUROCERAS ROTUNDICOSTA gen. et sp. nov. (Pl. XLI, figs. 1 a-1 c.)

This name is proposed for a small ammonite of unknown affinities. It has a rounded whorl, higher than wide, somewhat loosely coiled. Its inner whorls appear to be smooth or striate, and there are curved striations and subcostæ on the sides of the outer whorl; before these reach the venter they become stronger and rounded, and bend slightly forwards as they cross the venter.

The suture is fairly complicated, and shows an asymmetrical IL

somewhat resembling that of Platypleuroceras brevispina.

Dimensions.

Diameter. Whorl Height. Whorl Thickness. Umbilicus.
49 mm. 34 per cent. 26 per cent. 41 per cent.

The specimen is quite distinct from any figured species of which we are aware; it resembles to some extent certain Polymorphids like *P. peregrinum* (Haug in Wright), but has a more expanded whorl, and its suture is much more complicated; the ornamentation is also peculiar.

Holotype: A specimen from the *Jamesoni* Limestone of exposure 10, p. 610; J. W. T. Coll. This species is chosen as the genotype of *Peripleuroceras*.

UPTONIA JAMESONI (Sowerby). (Fig. 15 a, p. 647.)

Very common. This name is here applied to specimens identical with that figured by Wright. They have finely-ribbed inner whorls, with an early tuberculate stage; at a later stage the whorl becomes moderately high, with fairly fine curved ribs. The last whorl is heavier, bearing stronger ribs which curve gently forwards and cross the venter with a slight forward bend. Typically,

the suture has a rather symmetrical trifid IL, about equal in depth to EL (fig. 15 a).

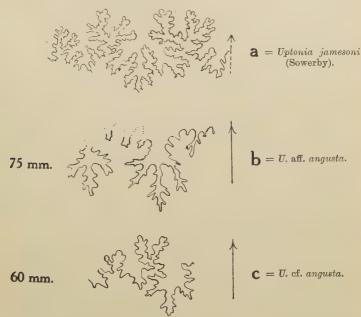
Dimensions of Wright's specimen.

Diameter. Whorl Height. Whorl Thickness. Umbilicus. 167 mm. 29 per cent. † 18 per cent. 46 per cent.

UPTONIA aff. ANGUSTA (Quenstedt). (Fig. 15 b.)

This name is applied by us to thin-whorled $Uptoni\alpha$ with fine ribs slightly curved. Sutures closely spaced, with narrow and symmetrical IL. U. angusta is usually associated with U. jamesoni at Radstock.

Fig. 15.—Sutures of Uptonia.



UPTONIA aff. REGNARDI (A. d'Orbigny).

- Besides typical specimens of this species (exposure 2, p. 605), a⁷more slender form is known from exposure 13, p. 611. These regnardi-like forms often have an outer whorl which resembles *U. jamesoni*, but is usually more slender.

UPTONIA DISTINCTA Sp. nov. (Pl. XLI, figs. 2 a & 2 b.)

An *Uptonia* which resembles *U. regnardi* in side view, the ribs having a sharp (*Oistoceras*-like) forward bend on the venter.

Dimensions.

Diameter. Whorl Height. Whorl Thickness. Umbilicus. 35 mm. 26 per cent. 19 per cent. 51 per cent.

Holotype: A specimen from the Jamesoni Limestone (?jamesoni) of Timsbury (exposure 2, p. 605); J. W. T. Coll.

Jamesonites reticulatus S. Buckman, exposure 13, p. 611. Jamesonites venustulus (Dumortier), exposure 1, p. 601.

Genus Platypleuroceras.

Typical members of this genus, that is the Platypleurocerasbrevispina group, have inner whorls rather heavily ribbed, becoming unituberculate at an early stage, a second (inner) row of tubercles usually appearing later. In many species the tubercles are reduced on the outer whorls, and frequently the outer tubercles alone are retained. At first the venter is smooth, then crossed by folds, and later by the coste. These changes in lateral and ventral ornament appear to take place independently of one another and of changes in whorl-shape in different series. The whorl in some species is fairly round; but in others the round-whorled stage is succeeded by a stage with a comparatively high whorl. Thus P. rotundum retains a round whorl, but has ribs which cross the venter; while P. grumbrecti retains the bituberculate condition, with a more elevated (that is, advanced) whorl-shape. It is probable that many more true species are represented at Radstock than are named here; the specific names indicate little more than a preliminary grouping of the forms.

All the forms of the *P.-brevispina* group agree generally in sutural characters; the IL is deep and narrow, asymmetrical, with

the ventral lobule of the lobe higher than the dorsal one.

PLATYPLEUROCERAS aff. ROTUNDUM (Quenstedt, 1849, pl. iv, fig. 17, & 1884, pl. xxxiii, fig. 14).

Typical specimens found at Radstock are rather small. In development, costæ are present by the diameter of 4 mm., and two rows of tubercles are present before the diameter of 12 mm. is reached. These tubercles disappear, or become feeble on the last whorl.

PLATYPLEUROCERAS (?) aff. ROTUNDUM (Quenstedt). (Fig. 16a.)

Compare Ammonites natrix rotundus Quenstedt, 1884, pl. xxxiii, fig. 11.

Larger specimens than the foregoing are possibly related to them; the whorl is more elevated, but the ribs still cross the venter with little diminution in strength. The outer whorl somewhat resembles *Uptonia jamesoni*.

PLATYPLEUROCERAS BREVISPINA (Sowerby). (Fig. 16 b.)

A form with a fairly round whorl, higher than broad, but differing from *P. rotundum* in having short tubercles on the last whorl, the outer tubercles being more prominent. The ribs cross the venter, but with a diminution in strength.

Fig. 16.—Sutures of Platypleuroceras.

PLATYPLEUROCERAS cf. GRUMBRECTI (Oppel).

The whorl height increases more rapidly than in preceding species, and two rows of tubercles are retained; the outer tubercles are not more prominent than the inner until the last half-whorl. The costæ are inclined, and do not cross the venter, except as low folds.

PLATYPLEUROCERAS BREVISPINOIDES sp. nov. (Pl. XL, figs. 2a-2b & text-fig. 16c, p. 649.)

Compare Ammonites brevispina Quenstedt, 1884, pl. xxxiii, fig. 10.

A somewhat thin form, the last whorl of which expands rapidly, passing from bituberculate to unituberculate. The inner whorls have strong distinct costæ at an early diameter, the outer tubercles appearing by the diameter of 12 mm., and the inner a whorl later. On the last whorl the inner tubercles are practically obsolete, and the outer tubercles very faint. In the holotype the costæ on the last whorl are first inclined slightly forwards, then radial, and finally reclined. For the first half of the last whorl the venter is almost smooth, after which it is crossed by folds of moderate strength.

The suture is similar to that of P. brevispina, but the IL is

deeper and narrower.

The dimensions of the holotype at two diameters are given in

the appended table (below).

Holotype: A specimen from the *Jamesoni* Limestone of Clandown (p. 601); J. W. T. Coll.

PLATYPLEUROCERAS cf. oblongum (Quenstedt, 1884, pl. xxxiii, figs. 1 & 7). (Fig. 16 d, p. 649.)

The specimens referred to this species differ from all those enumerated above in having no more than one row of tubercles, so far as can be determined, at any stage in development. The ribs rarely cross the venter, the whorl is high, and the venter fairly flat. The suture also differs rather widely from the other species that we have referred to this genus, and is more like that of *Uptonia jamesoni*.

DIMENSIONS OF VARIOUS SPECIES OF PLATYPLEUROCERAS.

	Diameter in mm.	Whorl Height per cent.	Whorl Thickness per cent.	Umbilicus per cent.
P. rotundum (Quensted		per cents	per contr	per conti
1849, pl. iv, fig. 17		24	24	58
P. aff. rotundum		24	22	56
P. ? aff. rotundum	. 133	25	20	52
P. brevispina	55	24	20	56
P. cf. grumbrecti	58	26	22	57
P. brevispinoides	81	26	24	51
	47 .	27	20	56

The dimensions given in the above table refer to Radstock specimens, unless otherwise stated.

? Platypleuroceras bituberculatum sp. nov. (Pl. XXXIX, figs. 3 a & 3 b.)

This name is proposed for an animonite that may be regarded as a homeomorph of *Crucilobiceras crucilobatum* S. Buckman, which it resembles very closely except in its suture.

It acquires distinct costæ by the diameter of 4 mm. and sharp outer tubercles by 8 mm. The inner row of tubercles does not appear until much later (15 mm.), but these become nearly as prominent as the outer. On the outer whorl the tubercles are connected by low costæ, which do not extend beyond the tubercles. The outer tubercles are situated on the extreme margin of the venter, and the inner about the middle of the whorl. The venter is smooth and somewhat flat.

The suture is simple, with an asymmetrical IL of the pattern characteristic of *Platypleuroceras*.

Dimensions.

Diameter. Whorl Height. Whorl Thickness. Umbilicus. 39 mm. 26 per cent. 23 per cent. 56 per cent.

This ammonite resembles some species of *Platypleuroceras* which are bituberculate, but retains the bituberculate stage longer than is usual in the genus, and it also differs in the position of the tubercles (especially of the inner tubercles). It should perhaps be referred to a new genus, but it may be regarded as a member of the Polymorphidæ with some relations to *Platypleuroceras*.

Holotype: A specimen from the *Jamesoni* Limestone (?) of exposure 10, p. 610; J. W. T. Coll. Another specimen found with *Polymorphites lineatus* at Rockhill (exposure 5, p. 607) makes it possible to fix the horizon more precisely as near the base of the

Jamesoni Limestone.

Tropidoceras masseanum (A. d'Orbigny). Below ibex, 4 (p. 607).

Acanthopleuroceras aff. valdani (A. d'Orbigny).

Acanthopleuroceres valdani (Wright, 'Lias Ammonites' pl. xlix, figs. 2-4); a form that represents a later stage than A. valdani (A. d'Orbigny). Post-tuberculate, post-carinate.

Acanthopleuroceras valdani (Oppel, 1853, pl. ii, figs. 2 a & b).

Acanthopleuroceras (?) aff. acteon (A. d'Orbigny).

ACANTHOPLEUROCERAS LEPIDUM sp. nov. (Pl. XL, figs. 1a & 1b.)

Dimensions.

Diameter. Whorl Height. Whorl Thickness. Umbilicus. 85 mm. 29 per cent. 22 per cent. 50 per cent.

Periphery rounded or convexifastigate, apparently postcarinate. Fairly closely costate from an early stage; costæ curved, swinging forwards on the periphery and in some cases uniting feebly with those of the opposite side. Apparently there are no tubercles on the inner whorls, but there is a tendency to form elongate tubercles on the inner margin of the last whorl. This tendency to form tubercles on the inner before the outer margin suggests a possible relationship to A. valdani; our species differs in this feature from A. actæon, which tends to develop the outer tubercles first. It may be related to A. rursicosta S. Buckman, but the ribs are not notably reclinate.

In general plan, the suture agrees with that of other species of *Acanthopleuroceras*. The form of IL is characteristic of the genus, but the ES is less equally divided. The suture on the whole is more complex than that of *A. valdani*.

Holotype: A specimen from the Valdani Limestone of Rad-

stock: J. W. T. Coll.

Family LIPAROCERATIDÆ.

Beaniceras aff. senile S. Buckman; from the upper part of the Valdani Limestone.

Liparoceras sparsicosta Trueman; 6 inches above the base of the Striatum Clays at Huish Quarry (13, p. 611).

Liparoceras cheltiense (Murchison). Valdani Limestone.

Liparoceras zieteni (Quenstedt).

Parinodiceras reineckii (Quenstedt).

Vicininodiceras simplicicosta Trueman.

Ægoceras aff. latæcosta (Sowerby). Capricornum Clay, Paulton.

Cf. Amblycoceras brevilobatum Trueman. Capricornum Clay, 30, p. 619.

Family LYTOCERATIDÆ.

Kallilytoceras interlineatum S. Buckman. Valdani Limestone; exposure 25 (p. 616) and 'Old Pit', Clandown.

Family PHYLLOCERATIDÆ.

Tragophylloceras numismale (Quenstedt). Tragophylloceras wechsleri (Pompeckj). Tragophylloceras ibex (Quenstedt). (?) Tragophylloceras loscombi (Sowerby).

Lamellibranchia.

Genus GRYPHÆA.

GRYPHÆA aff. DUMORTIERI Joly. (Fig. 17 a, p. 653.)

Common in the Angulata Zone. The degree of incurving varies: distinguished from Gr. incurva by the larger area of attachment. Dimensions of figured specimen: length=46 mm.; breadth=27 mm.; area of attachment, 12 mm. long; spiral angle about 70°.

GRYPHÆA aff. INCURVA Sowerby. Not common, but occasionally found in the *Bucklandi* Bed.

GRYPHEA INCURVA VAR. CRASSIRUGATA nov. (Fig. 17 c, p. 653.) Compare Gryphæa arcuata Dumortier.

Extremely common in the *Bucklandi* Bed and the *Spiriferina* Bed at Radstock; a similar variety occurs with typical *Gr. incurva* in Glamorgan, but much less abundantly. Characterized by regular, strong and rounded, concrescent ribs.

¹ Op. cit. pt. 2, 1867, pl. xiii, figs. 4 & 5 only.

Holotype: A specimen from the *Spiriferina* Bed at exposure 10, p. 610; British Museum (Natural History) no. L 40735, ex A. E. T. Coll.

GRYPHÆA OBLIQUA Goldfuss.

We apply this name to moderately wide forms, with a fairly prominent beak; sulcus feeble or absent. Shell ornamented by low concrescent ridges. Distinctly oblique. Dimensions of a typical specimen: length=52 mm.; breadth=43 mm., less than three-quarters of a whorl; spiral angle=about 60°.

Fig. 17.

a=Gryphæa aff. dumortieri Joly. Welton. Natural size.

b=G. aff. obliqua Goldfuss. Armatum Bed (raricostatoides), Kilmersdon Road Quarry. Two-thirds of the natural size.

 $\mathbf{c} = G.$ incurva var. crassirugata nov. Type. Spiriferina-walcotti Bed, Kilmersdon Road Quarry. Natural size.

This form occurs chiefly in the *Armatum* Bed: with it are associated specimens of similar proportions, but of rougher aspect, and possessing a prominent sulcus (fig. 17 b).

Generally, the specimens of *Gr. obliqua* appear to have become free at an early stage; but some specimens which remained attached longer assume the form of *Ostræa sportella* Dumortier.

GRYPHÆA cf. CYMBIUM Goldfuss.

Common in the *Jamesoni* Limestone. Moderately large shells, fairly smooth, sulcus more or less distinct. Not very oblique. Dimensions: length=90 mm.; breadth=58 mm.; spiral angle=about 65°. Not more than half a whorl.

GRYPHEA aff. CYMBIUM Goldfuss.

Compare Gryphæa obliqua Dumortier.1

More curved than the last, about a whorl. Post-obtusi.

¹ Op. cit. pt. 3, pl. xxii, fig. 5.

Lists of fossils other than Ammonites.	Planorbis Beds.	Angulata Beds.	Bucklandi Beds.	Turneri Clay.	Obtusum Nodules.	Raricostatum Clay.	Armatum Beds.	Jamesoni Limestone.	Valdani Limestone.	Striatum and Capricornum Clays.
Ichthyosaurus spp Plesiosaurus sp	×	×	×	1			_			
Dapedius dorsalis Agassiz Pholidophorus sp. Acrodus nobilis Buckland Hybodus reticulatus Agassiz	×	×	×							
Belemnoidea. Belemnites acutus Miller										
B. acutus Phillips, non Miller B. apicicurvatus Blainville B. breviformis Voltz B. bucklandi Phillips			×				 X	×	×	
B. charmouthensis Mayer B. clavatus Blainville B. cf. elegans Simpson B. cf. elongatus J. de C. Sowerby		 					×	××	×	×
B. grandævus Phillips (?) B. infundibulum Phillips B. cf. janus Dumortier	·	.	×		. × .			;	×	
B. junceus Phillips B. longissimus Miller B. milleri Phillips B. nitidus Phillips	.			·			. ×	×	 - ×	
B. oxyconus Quenstedt B. penicillatus J. de C. Sowerby B. umbilicatus Blainville B. ventroplanus Voltz						. ×				-
B. subdepressus Voltz (var. C, pl. vii, fig. 5				.,				×		. ×
Nautilus cf. araris Dumortier N. intermedius Sowerby N. cf. intermedius Sowerby N. simillimus Foord & Crick N. striatus Sowerby	.			 				· >		

	Planorbis and Angulata Zones.	Bucklandi Zone.	Armatum Bed.	Jamesoni & Valdani Limestones.	Striatum and Capricornum Clays.
GASTROPODA.1					
Actæonina ilminsterensis Moore					×
A. marginata (Simpson)					×
A. sp. Amberleya aff. acuminata (C. & D.)					×
A. emylius (A. d'Orbigny)	×		×		
A. aff. fidia (A. d'Orbigny)				×	
A. cf. gaudryana (A. d'Orbigny)	×				
A. imbricata (Sowerby) A. sp.				5	
A. sp.	×				×
Ataphrus (Turbo) bullatus (Moore)			×		
Bourguetia ef. liasina (Terquem)	×				
B. morencyana Piette B. turbinata (Stoliczka)	X				
Cryptænia ef. affinis Tate			×	×	Ì
U. cf. expansa (Sowerby)		×			
C. (?) solaroides (Sowerby)		×			
Discohelix sp.			×)
Katosira concinna McDonald & Trueman K. (Rigauxia) noguesi (Dumortier)			×		ì
Littorina cf. semiornata Goldfuss	×		^		
Patella ? cf. hennoquii Terquem			×		
Pitonillus conicus (A. d'Orbigny)			×		
Pleurotomaria ef. anglica (Sowerby)			X		ì
P. cf. odia (A. d'Orbigny) P. cf. obesula Tate		; ×	×		
P. cf. princeps Deslongchamps				×	
P. cf. rustica Deslongchamps			×		
Procerithium cf. dayi (Tate)			×		ļ
P. sp. Trochus epulus (A. d'Orbigny)			×	Y	
T. cf. escheri Münster			<u></u>	×	
T. geometricus Dumortier			×		
T. cf. glaber Koch				×	
T. cf. redcarense Tate	×				
Turbo bifurcatus Moore T. coronatus Moore		•••	×		
T. cyclostoma Benz					×
T. cf. itys (A. d'Orbigny)				×	
T. cf. leo A. d'Orbigny			×		
T. licas A. d'Orbigny T. marcousanus Dumortier			X		
T. metis Münster		1	×	X	
T. of. nireus A. d'Orbigny			X	X	-
T. cf. orion A. d'Orbigny			×		
Turritella cf. septemcincta Münster	X				
T. cf. zenkeni (Dunker) Zygopleura cf. intermedia (Terquem & Piette)	×	-			×
Z, (?) hedonia (A. d'Orbigny)				×	^
Z. sp. indet.	×				
Number of Species	10	3	23	12	6
Number of Species!					

 $^{^1}$ We are indebted to Dr. A. I. McDonald, F.G.S., for assistance in identifying the gastropods. Q. J. G. S. No. 324.

Planorbis Beds. Angulata Beds. Bucklandi Beds. Turneri Clay. Obtusum Nodules. Raricostatum Clay. Armatum Beds. Jamesomi Limestone. Striatum and Clamicomum Clays. Striatum and Clamicomum Clays.	Capricornam oraș
LAMELLIBRANCHIATA.	-
Anomia alpina Winkler	
A numismalis QuenstedtX	
A strictula Onnel	
Amening elongata (Romer)	
Astarte amalthei QuenstedtX	
A. camertonensis Moore	
A. cf. cingulata Terquem	
A. consobrina Chapuis & Dewalque	
A. oppeli Moore (non Andler)	
Avicula (Oxytoma) acuticosta Terquem & Piette	
Piette A. (O.) calva Schlænbach	
A. (O.) inæquivalvis Sowerby	
A. (O.) sinemuriensis A. d'Orbigny	
Cucullæa muensteri Goldfuss, Oppel	
Cardinia concinna (Stutchbury)	
C elongata (Dunker)	
C. flicheri Joly	
C. gigantea QuenstedtX	
C. hybrida (Sowerby)	
C. of. listeri (Sowerby)	
C. ovalis (Stutchbury) ×	
C. philea A. d'Orbigny, Dumortier	
C. rugulosa Tate Cardita consimilis Tate	
C. heberti Terquem	
Capricardia (Trapezium) cucullata Munster	
C. (T.) intermedia Moore	
Gervillia crenulata Quenstedt	
G. lævis J. Buckman	×
Goniomya heteropleura Agassiz	
G. hybrida (Münster)	X
, Gresslya galathea Agassiz	
Gr. cf. striata Agassiz	
Gryphæa cymbium Goldfuss	
Gr. dumortieri Joly, Trueman	
Gr. aff. incurva Sowerby	
Gr. incurva var. crassirugata Trueman	
Gr. obliqua Goldfuss	
Hinnites (Eopecten) angularis Tate	
Inoceranus incurvatus Tate	×
I. cf. substriatus Münster	^
I. ventricosus (J. de C. Sowerby)	

		Planorbis Beds.	Angulata Beds.	Bucklandi Beds.	Turneri Clay.	Obtusum Nodules.	Raricostatum Clay.	Armatum Beds.	Jamesoni Limestone.	Valdani Limestone.	Striatum and Capricornum Clays.
	Leda galathea (A. d'Orbigny)							×			
	L. minor (Simpson) L. subovalis (Goldfuss)										X
	Lima cf. duplum Quenstedt						_				
	L. dunravenensis Tawney	×					~	X	×		
	L. cf. eucharis A. d'Orbigny									×	
	L. gigantea (Sowerby)		×	X							
	L. hettangiensis Terquem		×				-	- }			
1	L. pectinoides (Sowerby)		×			i				,	
٠,	L. punctata (Sowerby)			×				ļ			
	L. succincta (Schlotheim) L. terquemi Tate		×			- {					
1	Limea acuticosta Münster	×			ĺ	- {					
1	L. cristata Dumortier						• •	×	×		
- 1	T inlines a Description									, X i	
	Macrodon hettangiensis (Terquem)	X									
	M. cf. pulchellus Tate						. 1		X		
	M. pullus Terquem		\times		- 1			ı	i		
	M. stricklandi Tate					!	'		×		1
1	Modiola hillanoides Chapuis & Dewalque M. numismalis Oppel	٠٠٠]	\times					- 1		- 1	1
	M. cf. scalprum (Sowerby)	• • •		^		i			j	1	
1	34 7 7 110			X		• • •	^	×			
-	74 7 III. 0 TD' 11		X			i			- }		1
	Ostrea ef. arietis Quenstedt							\times			
1	O. brannoviensis Dumortier		}					×	×	- 1	
	O. electra A. d'Orbigny, Dumortier		\times								
1	O. goldfussi Bronn	;		\times							ŀ
-	O. irregularis Munster O. liassica Striekland	. '	×			1					
	O. multicostata Terquem	X			1						
	O. sportella Dumortier	^i	^			- 1			\times		
	Pecten (Chlamys) æqualis Quenstedt			×							
	P. (Chl.) acutiradiatus Münster			X		-					1
	P. (Chl.) acuticostatus Dumortier			.					×		
	P. (Entolium) calvus Goldfuss		×						1		
	P. (Chlamys) dispar Terquem		• • •	×		1	1	١.			
	P. (Entolium) cf. frontalis Dumortier P. (E.) hehli A. d'Orbigny	* *					•• •		× :	×	1
1	P. (E.) liasinus Nyst			X :	×				×		1
	P. (Chlamys) pollux A. d'Orbigny	× .					1		^		
.	P. (Chl.) cf. priscus Schlotheim			×			1		-		
	P. (Camptonectes) punctatissimus Quenstedt.		X	:			1				
	P. (Entolium) securis Dumortier	X							1		
	P. (E.) substrictus Romer					٠					X
i	P. (Chl.) tertarius Schlotheim		,	_							
1	P. (Chl.) textorius Schlotheim			^					i		
1										_	

	Planorbis Beds.	Angulata Beds.	Bucklandi Beds.	Turneri Clay.	Obtusum Nodules.	Raricostatum Clay.	Armatum Beds.	Jamesoni Limestone.	Valdani limestone.	Striatum and Capricornum Clays.
Pecten (Chlamys) textorius Quenstedt (' Der Jura', pl. xviii, fig. 17)			. , .				×	×		
P. (Chl.) texturatus Munster Perna cf. infraliassica Quenstedt	×					×		×		
Ph. fortunata Dumortier Ph. glabra Agassiz Ph. pentricoga (Agassiz), Dumortier	,	×	×							
Pinna folium Young & Bird P. cf. inflata Chapman & Dewalque P. comistriata Terquem		×					×	×		
Pleuronya cf. angusta Agassiz Pl. crassa Agassiz Pl. jauberti Dumortier		×				×		×	-	1
Pl. liasina (Schubler) Pl. macilenta Dumortier Pl. striatula Agassiz			×				×	×		1
Pl. struttula Agassiz Pl. otcasi Dumortier Plicatula deslongchampsi Terquem & Piette								. ×	×	
Pl. hettangiensis Terquem & Piette	. ×	:\×	×				. ×			
Pl. (Harpas) nitidus Dumortier Pl. sarcinula Münster Pl. of. spinosa Sowerby							. >		< >	<
Protocardia oxynoti (Quenstedt) Pr. phillipiana (Dunker) Unicardiam hombar (Quenstedt)	. >				. -				>	<
U. cardioides (Phillips) U. rugosum (Dunker)	-	<				>	< >			1
Brachiopoda.					1					1
Cincta conocollis (Rau)	1.			-			3	×	×	
C. dives S. Buckman C. inops S. Buckman C. misera S. Buckman									X	
C. numismalis (Valenciennes) C. nummata S. Buckman C. nummosa S. Buckman									×	
C. obolus S. Buckman									×	
C. pauper S. Buckman C. paupercula S. Buckman C. pernummus S. Buckman									×	

	[. 1			1		1		
		1						e e		9.V.
					00	Ly.		Jamesoni Limestone.	aldani Limestone.	Ē
	m	200	Bucklandi Beds.		Obtusum Nodules.	Ruricostatum Clay		set	sto	ntum and
	Planorbis Beds.	Angulata Beds.	3e(dr	2	Armatum Bed.	n	nei	ر ا
	B	P	i I	[g	N	m	Ã,	Ţ.	i.	triatum and
	is	ta	nd	0	n	at	m	:3:	ī .ī	200
	r.	la	las	37.2	u	ost	n_t	303	r.n.	711
	m	gu	ch	1.30	118	ric	ua	nes	de	ia
	Pla	421	Bu	Turneri Clay.	190	30	1.4	an	a	347
				-		7	A	2		
Cincta pernumismalis S. Buckman								×		
C. pinguis S. Buckman							X			
C. quadrans S. Buckman								X		
C. sestertius S. Buckman							×	· `		
Rhynchonella (Squamirhynchia) alberti										
Oppel									X	
Rh. (Piarorhynchia) aliena Rau							V		-	
Rh. (Squamirhynchia) belemnitica (Quen-							^			
stedt)			×							
Rh. (Cuneirhynchia) dalmasi Dumortier								V		
Rh. (Rimirhynchia) elevata S. Buckman								×		
Rh. (Furcirhynchia) furcillata (Theodori) .									×	
Rh. (Cuneirhynchia) persinuata Rau								×	^	
Rh. (Piarorhynchia) radstockiensis Davidson			X							
Rh.(Rimirhynchia) rimosiformis S.Buckman							· V	l v		
Rh. (? Quadratirhynchia) rufimontana	1						^			
(Quenstedt)									×	
Rh. (Squamirhynchia) squamiplex (Quen-										
stedt)										
Rh. (Tetrarhynchia) cf. tetrahedra (Sowerby)						^			~	
Rh. (Piarorhynchia) variabilis (Schlotheim)									X	
Spiriferina ef. hartmanni (Zieten)							X	^		
Sp. cf. rostrata (Schlotheim)										
Sp. tumida (Quenstedt)				X			X			
Sp. tumtaa (Quensteat)		1	×							
Sp. verrucosa (von Buch)							X			
Sp. walcotti (J. de C. Sowerby)			X							
T. basilica Oppel									V	
T. davidsoni Haime									×	
T. ovatissima Quenstedt							1	V		
T. radstockiensis Davidson							X	×		
T. sinemuriensis Oppel							~	1		
T. subovoides Ræmer								X	~	
T. subovoides Roemer, Deslongchamps								×	^	
Zeilleria arietis Oppel	1	1	X				V	V		
Z. (Ornithella) crithea (A. d'Orbigny)							^	×		
Z. darwini (Deslongchamps)			***			***	~	^		
Z. ef. engelhardti (Oppel)			·				_			
7 (Omithella) himidula (Simpson)	1		1	1		1	1			
Z. (Ornithella) hispidula (Simpson) Z. cf. mutabilis (Oppel)							1			
Z. pietteana (Oppel)										
Z. (Ornithella) sarthacensis (A. d'Orbigny)		1	1							
Z. (Ornithella) subdigona (Oppel)										
Z. vicinalis (Quenstedt)							~			
Z. (Aulacothyris) waterhousi (Davidson)				* * *			^			
	[_	!			1 _	,		(

	Planorbis Beds.	Angulata Beds.	Bucklandi Beds.	Turneri Clay.	Obtusum Nodules.	Raricostatum Clay.	Armatum Beds.	Jamesoni Limestone.	Valdani Limestone.	Striatum and Capricornum Clays.
Bryozoa. Berenicea archiaci (Haime) Stomatopora dichotoma (Lamouroux)					ļ	i 	1	×	×	1
Annelida. Ditrupa etalensis (Piette) D. quinquesulcata (Münster) Serpula limax Goldfuss S. plicatilis Goldfuss S. tricristata Goldfuss		×					×	×		
Crinoidea. Isocrinus angulatus (Oppel) I. jurensis (Quenstedt) I. psilonoti (Quenstedt) I. tuberculatus (Miller) I. scalaris Goldfuss ('Petrefact. Germ.' pl. liii, fig. 4)	. ×		. ×	.	.		×		· ··	. ×
ECHINOIDEA. Cidaris arietis (Quenstedt) Diademopsis bowerbanki (Wright) Pseudodiadema slateri Blake	>							. >	1	
ACTINOZOA. Heterastræa insignis Duncan Montlivaltia guettardi Blainville M. rugosa Wright		>	\ \ \ .				×			

VII. BIBLIOGRAPHY OF THE RADSTOCK LIAS.

Bristow, H. W. (1876). In H. B. Woodward (1876) p. 97.
Buckman, S. S. (1907). 'Some Species of the Genus Cincta' Proc. Cotteswold
Nat. F. C. vol. xvi, p. 41.
Do. (1917). 'Jurassic Chronology—I: Lias' Q. J. G. S. vol. lxxiii,

Do. (1917). Gurasole Ch.

p. 2667.

Do. (1910-25). 'Type Ammonites' (in course of publication).

CANTEILL, T. C., & PRINGLE, J. (1914). 'On a Boring for Coal at Hemington' Geol. Surv. Summary of Progress for 1913, p. 98.

CONYBEARE, W. D., & PHILLIPS, W. (1822). 'Outlines of the Geology of England & Wales' (Paulton, p. 262).

W. (1920). Trans. Geol. Soc. ser. 2, vol. iii, p. 245.

- McDonald, A. I., & Trueman, A. E. (1921). 'The Evolution of certain Liassic Gastropods' Q. J. G. S. vol. lxxvii, p. 297.
- MOORE, C. (1861). 'On the Zones of the Lower Lias & the Avicula-contorta Zone'
 - Q. J. G. S. vol. xvii, p. 483 (Paulton).

 On the Middle & Upper Lias of the South-West of England'
 Proc. Somerset Arch. & Nat. Hist. Soc. vol. xiii, p. 154.

 On Abnormal Conditions of Secondary Rocks when associated (1866).
 - Do. (1867).with the Somersetshire & South Wales Coal-Basins, &c.' Q. J. G. S. vol. xxiii, p. 449.
- REYNOLDS, S. H. (1912). 'A Geological Excursion Handbook for the Bristol District ' Bristol. [2nd ed. 1921.]
 - Do. & TUTCHER, J. W. (1919). 'Report of an Excursion to the Bristol District' Proc. Geol. Assoc. vol. xxx, p. 114.
- RICHARDSON, L. (1907). 'The Inferior Oolite, &c., of the Bath-Doulting District' Q. J. G. S. vol. lxiii, p. 383 (Timsbury Sleight, p. 413).

 Do. (1909). 'Report of an Excursion to the Frome District, Somerset'
 - Proc. Geol. Assoc. vol. xxi, p. 222 (Dunkerton & Vobster).
 - 'The Mesozoic Rocks of Gloucestershire & Somerset' Do.
 - Geology in the Field, Geol. Assoc., p. 329.

 911). 'The Rhætic & Contiguous Deposits of West, Mid, & Part of East Somerset' Q. J. G. S. vol. lxvii, p. 1 (Dunkerton, (1911).Do. p. 67).
- 'On the Lias about Radstock' Q. J. G. S. vol. xxxi, p. 493. TATE, R. (1875).
- Tawnex, E. B. (1875). 'Notes on the Lias of the Neighbourhood of Radstock'
 Proc. Bristol Nat. Soc. ser. 2, vol. i, p. 167.

 Do. (1878). 'On the supposed Inferior Colite at Branch Huish,
 Radstock' Proc. Bristol Nat. Soc. ser. 2, vol. iii, p. 175.
- TRUEMAN, A. E. (1921). 'The Liassic Rocks of Somerset' Rep. Brit. Assoc. 1920 (Cardiff), p. 356.
 - (1922). 'The Use of Gryphæa in the Correlation of the Lower Lias' Geol. Mag. vol. lix, p. 256. Do.
- . Tutcher, J. W. (1917). Appendix to paper by S. S. Buckman, 1917: 'The Zonal Sequence in the Lower Lias (Lower part)' Q. J. G. S. vol. lxxiii, p. 278.
 - WALCOTT, J. (1799). 'Description & Figures of Petrifactions found in the Quarries, &c. near Bath.
 - WILLIAMS, D. M., & TRUEMAN, A. E. (1925). 'Studies in the Ammonites of the Family Echioceratidæ' Proc. Roy. Soc. Edin. vol. liii, p. 699.
 - WINWOOD, H. H. (1908). 'New Branch Line of the Great Western Railway from Camerton to Limpley Stoke' Proc. Bath & Dist. Branch of Somerset Arch. & N. H. Soc. vol. i, p. 195 (Dunkerton).
 - WOODWARD, H. B. (1876). 'Geology of East Somerset, &c.' Mem. Geol. Surv.
 Do. (1893). 'The Lias of England & Wales' Mem. Geol. Surv.
 - pp. 126-136, 262, &c. (1908). 'The New Great Western Branch Railway from Camerton to Limpley Stoke, Somerset' Geol. Surv. Summary of Do. Progress for 1907, p. 155 (Dunkerton)

EXPLANATION OF PLATES XXXVIII-XLI.

[All figures are of the natural size, except where otherwise stated.]

PLATE XXXVIII.

- Fig. 1. Arnioceras hodderi sp. nov. Holotype. 1 a, viewed from the side; 1 b, from the front; 1 c, from the side. From the Bucklandi Bed (sauzeanum), Hodder's Quarry, Timsbury. J. W. T. Coll. (See p. 639.)
 - 2. Pararniocerus sp. Young forms; 2a, from the side; 2b, from the front; 2c, a smaller specimen, × 1.5. Bucklandi Bed, Radstock. J. W. T. Coll. (See p. 640.)

PLATE XXXIX.

Fig. 1. Arnioceras crassicosta sp. nov. Holotype. 1 a, from the side; 1 b, whorl shape. From the hard band at the base of the Obtusum Bed, Timsbury (2). Brit. Mus. Coll. no. C 26789 (ex A. E. T. Coll.). (See p. 637.)

 Arnioceras notatum sp. nov. Holotype. 2a, from the side; 2b, from the back. From the Bucklandi Bed, Rockhill (5). J. W. T. Coll.

(See p. 638.)

3. Platypleuroceras bituberculatum sp. nov. Holotype. 3 a, from the side; 3 b, from the back. From the Jamesoni Limestone (Polymorphites), Kilmersdon Road Quarry (10). J. W. T. Coll. (See p. 650.)

PLATE XL.

Fig. 1. Acanthopleuroceras lepidum sp. nov. Holotype. 1 a, from the side; 1 b, from the back. From the Valdani Limestone, Radstock. J. W. T. Coll. (See p. 651.)

Platypleuroceras brevispinoides sp. nov. Holotype. 2a, from the side;
 b, from the back. From the Jamesoni Limestone (brevispina),

Clandown Quarry (1). J. W. T. Coll. (See p. 650.)

PLATE XLI.

Fig. 1. Peripleuroceras rotundicosta gen. et sp. nov. Genotype, holotype: 1 a, 1 b, side views of the same specimen; 1 c, from the back. From the Jamesoni Limestone, Kilmersdon Road Quarry (10). J. W. T. Coll. (See p. 646.)

2. Uptonia distincta sp. nov. Holotype. 2 a, from the side; 2 b, from the back. From the Jamesoni Limestone (?jamesoni), Timsbury (2).

J. W. T. Coll. (See p. 647.)

3. Oxynoticeras williamsi sp. nov. Holotype. 3 a, from the side; 3 b, from the front. From the Armatum Bed, Rockhill Quarry (5). Brit. Mus. Coll. no. C 26788 (ex D. M. Williams Coll.). (See p. 644.)

DISCUSSION.

The following is the condensation of a letter sent by Mr. S. S. BUCKMAN, and read in full by the SECRETARY:—

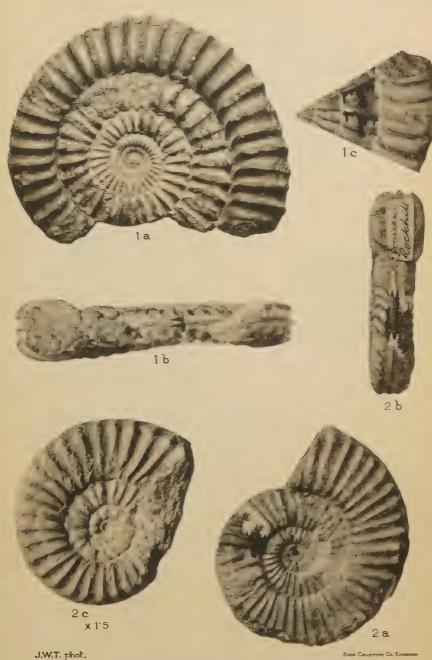
This is a paper which may confidently be welcomed. The work of the Authors is already well known. Mr. Tutcher has made a lifelong study of the

district, and Dr. Trueman has proved his ability as a palæontologist.

One point that this paper should bring out is that of non-sequences; for the Radstock area is one of the best for illustration of this phenomenon. Doubt has been expressed lately as to there being such a phenomenon as non-sequence. This is a very rash position to take up, for, after all, there is no difference, except in degree, between a non-sequence and an unconformity. In the latter, the stratal discordance is so great as to be obvious at once. In the former, the stratal discordance is so feeble as not to be obvious in one exposure—only to be noted by combining exposures. In the Cotteswolds by this method I found that the inappreciable non-conformity, or, as it was called for short, non-sequence, was a discordance or departure from parallelism of 7 feet per mile. The Authors may be able to give similar figures; more likely they may not, because the area described by them does not stretch over many miles like the Cotteswolds.

Those who attack non-sequences write and speak as if 'zone' and 'hemera' were interchangeable terms; and they fail to understand that, knowing from other evidence that there must have been a given interval of time, one is able to point out that the fauna proper to such a time-interval

QUART. JOURN. GEOL. Soc. Vol. LXXXI, PL. XXXVIII.



ARNIOCERAS and PARARNIOCERAS.



QUART. JOURN. GEOL. Soc. Vol. LXXXI, PL. XXXIX.



ARNIOCERAS and PLATYPLEUROCERAS.



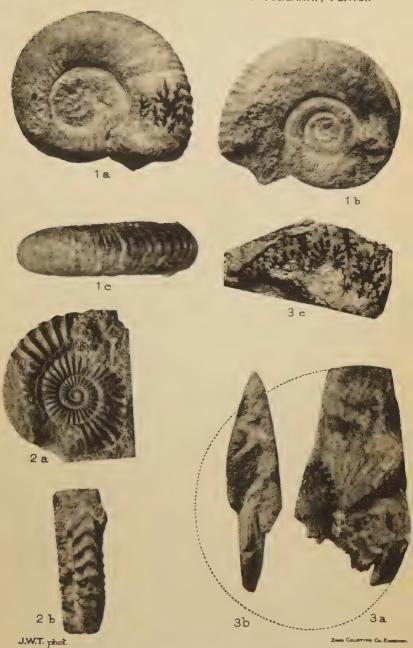
QUART. JOURN. GEOL. Soc. Vol.LXXXI, PL.XL.



ACANTHOPLEUROCERAS and PLATYPLEUROCERAS.



QUART. JOURN. GEOL. Soc. Vol.LXXXI, PL.XII.



PERIPLEUROCERAS, UPTONIA, and OXYNOTICERAS.



is absent from a given locality. But the fauna is not at all necessary to prove the time-interval. Dr. Lee, for instance, recognizes the time of niortensis in the Hebrides, applying the term to a date for an unfossiliferous deposit of some 70 feet.

Another idea which opposes non-sequence is that of a hemera being a short space of time. Geologically it is, relatively it is not. Just as a light-year is the unit of astronomical distance, so is a hemera the unit of geological chronology. What is to prevent us from claiming that a hemera, the unit of geological chronology, is a million years? Faunal development and dispersal in the time of a hemera demand what, to us, is a very long time; but, as compared with the time required for geological history, a million years is a mere nothing.

Dr. W. D. Lang, in joining with the President in welcoming the paper and congratulating the Authors on their lucid exposition, said that he would like to ask the Authors whether the ammonites of the A. Turneri group occurring in the Radstock Turneri Clays could be identified with sufficient precision to indicate whether they belonged to the true A. Turneri group, occurring in Dorset immediately above M. birchi, or to a very similar assemblage of much earlier date, lying, in fact, only a little above the Euagassiceras fauna, and separated from the higher zone by several ammonite faunas and some 30 feet of sediment.

The Authors, too, had appeared to imply that the beds of the Dorset-coast Lias were seen to be of a general uniform thickness when traced laterally. This was by no means the case. The 'Striatum Beds', for instance, which the Authors had discussed in this connexion, varied from more than 100 feet at Westhay to about 60 feet on Stonebarrow, and, so far as could be judged from what remained of them, to considerably less on Black Ven. The speaker suggested that this variation might be partly due to the compression of the clays, if the amount of sediment subsequently piled upon them had varied in different spots.

The paper had brought into prominence the phenomenon of non-sequences, and he wished to protest against the disposition of geologists either practically to deny non-sequences on the one hand, or, on the other hand, to accept uncritically all those that Mr. Buckman demanded. The Authors had demonstrated one non-sequence—that between the lower 'Angulata Beds' and the upper 'Bucklandi Beds' (involving a larger gap than those unacquainted with the detailed Lias might suppose), which occurred in the middle of a limestone-band. A non-sequence, as difficult to detect lithically, occurred in the Dorset-coast Lias, one which Mr. Buckman had demanded on palæontological grounds. The speaker had at one time seen no reason for recognizing it, yet now strongly advocated it. On the other hand, he was not prepared to admit some other non-sequences demanded by Mr. Buckman in the Dorset-coast succession. Yet if, in his zeal, Mr. Buckman overstated the case, that was no argument against there being a case to overstate, or against our being grateful to him for first recognizing the frequency of non-sequences in the Lias; and that there was a strong case for these non-sequences the Authors had fully proved in the present paper.

Dr. L. F. Spath congratulated the Authors on an excellent paper and the Society on receiving a valuable contribution. He welcomed Dr. Trueman's adoption of 'popular' names, as shown in the abstract, for the purpose of reading and discussing the paper. There was an obvious difficulty, however, in using certain of these terms in an admittedly wrong sense, as the Authors themselves pointed out. He instanced the case of Ammonites armatus which was used to designate and give a spurious definition to a bed above the Raricostatum Clay, whereas, in reality, this ammonite was of

pre-raricostatus age.

Dr. A. Morley Davies spoke with mixed feelings—thankfulness that the publication of valuable research, expected for many years past, was at last in sight, and regret that the senior Author was prevented by ill-health from being present. He asked Dr. Trueman whether some of the episodes described might not be due to wider causes than the local movements in the Mendips: derived Echiocerates, for instance, were found in the Jamesoni Zone in the Calvert boring, in an area well outside the Armorican folding. On the general question which had been raised of restricted geographical range versus denudation as an explanation of the discontinuous distribution of certain ammonite faunas, every case should be considered on its merits. Where an exceptionally rare and discontinuous fauna came at the top of a series of which each successively lower fauna showed a wider and more continuous geographical range, denudation after gentle folding was the simple and obvious explanation.

Prof. H. L. Hawkins laid emphasis on the interest of the work, in that it traced down into the Lias on the northern side of the Mendips conditions of contemporary erosion and folding comparable with those established by Mr. L. Richardson in the Inferior Oolite of the region south of that axis of upheaval. The circumstances seemed strangely complementary, since in the Radstock area the basal 'Sun-Bed' seemed the most persistent and uniform layer in the sequence; while around Doulting and Bruton the Doulting Stone, at the top of the Inferior Oolite, appeared to be the most reliable horizon. It would seem that the district must have been spasmodically unstable from the close of the Rhætic to the commencement of Bathonian times. He urged the importance of detailed stratigraphical studies of this nature, in providing clues as

to the technique of tectonic movement.

Mr. S. W. Wooldridge said that Mr. Buckman, in his contribution to the discussion, had seen fit to introduce the general question of non-sequences. To deny the existence of non-sequences would be to take up an impossible attitude, but he questioned the validity of a certain class of non-sequences based solely on faunal evidence. The paper to which they had just listened contained convincing evidence of slight angular discordance and erosive breaks to which few would be disposed to deny the term 'non-sequence'. The invisible, or, as the speaker would prefer to term them, hypothetical breaks, were in very different case. Workers

on modern zonal stratigraphy seemingly failed to realize that the conception of long-continued and spasmodic sedimentation was not incompatible with rapid accumulation in the unit or bed. The combination of the two ideas certainly implied the existence of many non-sequences, but it also carried other consequences. If a thin sheet of sediment accumulated rapidly over a fairly wide area it might well entomb different faunas at different places. That sediment could so accumulate in a relatively short time was manifest from the study of certain ancient sedimentary rhythms, no less than from the phenomena of recent sedimentation. The explanation of such a case by modern methods would probably necessitate the creation of several non-sequences of the 'invisible' order. How was it possible to be sure that such errors had not crept in, in the case of recent zonal studies?

Mr. G. W. Lamplugh remarked that all clastic sediments were, from their nature, lenticular, though the expansiveness of lenticles of small thickness was often surprisingly great. This might be because, in so many cases, the line of outcrop coincided approximately with the longer axis of the area of deposition. occurrence locally of long periods of practically uninterrupted sedimentation, for which we had evidence, seemed to the speaker more remarkable than the occurrence of interrupted sedimentation such as the Authors had so ably described. In our current-swept English seas there were few places, except the deep trough between the Isle of Man and Ireland, where continuous local sedimentation could be at present in progress. It was recognized that the area studied by the Authors lay near the margin of the Liassic Sea, and he would ask whether the submarine banking and shifting of sediments might account for the observed phenomena without necessitating the very shallow folding on which they relied.

The PRESIDENT (Dr. J. W. EVANS) expressed his appreciation of the value of the paper and the interest of the discussion that

had followed

From the tectonic standpoint it was of great importance to make sure whether the non-sequences really corresponded to folding movements. There could be no doubt that these deposits were laid down in a sea with strong tidal currents, which would tend to produce erosion in some areas and accumulations, forming banks, in others. A change of geographical conditions would result in a different system of currents, so that elevations previously formed might be worn away, and ultimately a non-sequence come into existence. On the other hand, the deposition of thick masses of sediments would, in accordance with the principles of isostasy, result in earth-movements which could not well be regarded as a continuation of Hercynian activity.

Dr. Trueman, replying briefly to the points raised in the discussion, said that he did not propose to deal with the criticisms of the principle of dissimilar faunas to which reference had been made. For his own part, ten years ago he attempted to explain discrepancies in the distribution of certain ammonites in the Lias

of the Midlands as the result of variations in the physical conditions, but further study of the facts convinced him that such an

explanation was untenable.

With regard to Mr. Wooldridge's remarks, he felt that the latter's views were illogical; for he noted that Mr. Wooldridge was prepared to accord a greater length of time to the deposition of the Lias than the thickness of the sediments appeared to require, yet he considered that modern work proved that sedimentation often proceeded more rapidly than had been supposed: presumably, therefore, sedimentation must have been intermittent.

Replying to a question asked by Dr. Lang, Dr. Trueman said that the ammonites of the *Turneri* Clay were badly preserved, but included forms closely resembling those of the upper horizon at Lyme Regis. He had not been able definitely to correlate the

Arniocerates.

He agreed with Dr. Spath that there were difficulties in using such names as *Bucklandi* Bed, *Turneri* Clay, etc., but felt that their use made the general results of the paper available for those unacquainted with more modern Jurassic terminology; he considered that confusion need not arise if it were made clear that the names were so used.

With reference to the point raised by Dr. Davies, doubtless the movements along the Mendip Axis were related to wider movements affecting other regions; nevertheless, he considered that the changes in thickness and in the development of the various

beds could only be due to differential movements.

In reply to Mr. Lamplugh, Dr. Trueman said that the distribution of the faunas within such a stratum as the *Raricostatum* Clay made it apparent that the conditions were due mainly to earth-movements and to denudation. The Authors were in substantial agreement with Mr. Lamplugh as to the origin and relations of the phosphatic nodule-beds.

The Authors had considered the possibility of current action suggested by the President, but decided that the distribution of the *Planorbis* and *Angulata* Zones, for example, was too peculiar

to have resulted in that way.

Dr. Trueman regretted the absence, owing to ill-health, of his collaborator Mr. Tutcher, but was gratified to hear the kind references to the latter's work. He wished to say that he considered it a great privilege to be associated with Mr. Tutcher in this paper.

19. On some Occurrences of Spherulitic Siderite and other CARBONATES in SEDIMENTS. By EDMONDSON SPENCER, A.R.C.S., A.R.S.M., B.Sc., Ph.D., F.I.C., F.G.S. (Read June 10th, 1925.)

[PLATES XLII & XLIII.]

CONTENTS.

		Page
I.	Introduction, and Summary of Earlier Work	667
II.	Description of Spherulites	670
	(1) The Fairlight Clays.	
	(2) Upper Coal Measures of the Midlands.	
	(3) South Wales Coalfield.	
	(4) Wankie Coalfield (Rhodesia).	
	(5) Indian Coal Measures.	
HI.	Spherulites with Radiolaria in Rhombohedral Carbonates,	
	Santo Domingo (Portugal)	683
IV.	Origin of these Structures	684
	Relation to Clay-Ironstone.	
	Comparison with Oolitic Ironstone.	
V.	References	692
VI.	Appendix. Form of the Surface of Contact between Two	
	Interfering Spherulites	693

I. INTRODUCTION, AND SUMMARY OF EARLIER WORK.

MINERAL crystallizations possessing a radiate or divergent form are of common occurrence in certain types of igneous rocks, and to a more limited extent in sedimentary rocks. In igneous rocks these structures were first examined and described by H. Vogelsang (1),1 who gave to them the name of 'spherulitic structures', a term which has since been employed by petrologists for these igneous rock-growths in particular and for similar structures in general.

J. P. Iddings (2), in 1891, in a review of these igneous spherulites, pointed out that their essential feature was crystallization outwards from a centre or from a number of neighbouring centres. with a divergent or radiate arrangement, and that any concentric zoning or banding present was incidental to the radiate growth, since such bands or zones become truncated at points of contact with an obstacle, or with an adjacent spherulite.

Dr. Alfred Harker (3), in his 'Natural History of Igneous Rocks', discussed these igneous structures, and suggested that they had been formed by relatively rapid crystallization from saturated or supersaturated solutions.

In sedimentary rocks, spherulitic structures occur sometimes in

¹ Numerals in parentheses correspond with those in the list of references, § V, pp. 692-93.

the form of large isolated individuals, and sometimes as colonies of small interfering units. The latter variety which, on the one hand, possesses many of the features of igneous spherulites, appears to pass gradually, on the other hand, by an increase in the amount

of zoning or banding, into true oolitic structures.

Modern research in colloid chemistry has brought new facts to bear on the relationship between these radiate and concentric structures in rocks. Heinrich Schade (4 & 5), in 1909–10, in an examination of the structure and composition of gallstones, found that the structure was radial if the composition corresponded to 80 per cent. or more of pure cholesterin. With a lower cholesterin content a concentric structure tended to develop, and with less than 25 per cent. the concretions showed perfect concentric lamination, as in the case of true oolitic structures. The production of a laminated structure appears, therefore, to be due to the precipitation or separation of other substances along with the cholesterin.

The experiments of R. E. Liesegang (6), who allowed a silvernitrate solution to diffuse into a gelatine gel containing potassium bichromate, are well known. He observed that the precipitate formed was not, as might have been expected, uniformly distributed in the gel, but arranged in bands or zones with clear spaces of gel between them. The application of this phenomenon to explain many of the banded or zoned structures in rocks, etc., became at once apparent. Such structures might have been produced by diffusion in a gel medium without the necessity for a periodic variation in the 'food-supply' hitherto assumed.

In 1916, S. C. Bradford (7-13) put forward a plausible explanation of the above phenomenon, based on the theory that the solute in the gel became locally adsorbed by the precipitate produced. Bradford pointed out that the degree of banding was dependent on the nature and state of subdivision of the precipitate. A very fine or dense precipitate may impede diffusion of the precipitating reagent to such a degree that banding does not occur. On the other hand, a very coarse precipitate does not possess a sufficient specific surface to bring about the necessary adsorption of the reagent within the gel, and precipitation is again uniform, without banding. Optimum conditions for stratification appear to exist when the precipitate takes the form of microscopic 'spherulites' or 'spherites'; these bodies possess a large specific surface (and therefore a high adsorption coefficient). Bradford believes that gels themselves consist of microscopic spherulites and that 'gelation' is a crystallization phenomenon. In conformity with this view, he has recently succeeded in crystallizing gelatine in the form of microscopic spherulites (up to 6μ in diameter) which show a distinct black cross under crossed nicols.1

¹ An attempt to apply the principles of the Liesegang phenomenon to the origin of zoned or banded rock-structures of spherulitic or colitic type involves the difficulty that there is little or no evidence of diffusion of a hypertonic precipitating reagent within the medium.

W. H. Bucher (14), in a recent paper on oolites and spherulites, discussed the relationship between these structures, and reviewed a number of occurrences of spherulites and oolites in various minerals. Oxides and carbonate minerals most commonly assume these concretionary forms. Of these, the oolitic form is by far the most abundant, probably because mineral precipitations or crystallizations in sediments are usually yielded by solutions containing more than one constituent. The same author cites two instances of carbonate minerals assuming a spherulitic form:

(a) spherulites of calcium carbonate, up to 1 cm. in diameter, in the Miocene limestone of the Rhine valley; and (b) spherulites of siderite in cavities in basalt.

To the examples cited by him, the following occurrences may be added:—

(a) Calcium carbonate.—Numerous instances might be mentioned where onlitic structures in this mineral possess a more or less prominent radial arrangement. Some of the concretions figured by E. Kalkowsky (15), and described as 'ooliths', appear to possess many of the features of spherulites. The structure is prominently radial, with concentric zones which become truncated along the contact-surface between interfering units (see his pl. iv, fig. 4). G. Abbott (16) described large concretions from the Magnesian Limestone of Sunderland: many of these possess a pronounced radial structure.

(b) Dolomite.—Sir Aubrey Strahan (17) described the passage of a coal-seam into a spherulitic form of dolomite in the Coal

Measures of the Wirral peninsula.

(c) Sideroplesite.—An occurrence of crystals or concretions of sideroplesite in the Glenboig Fireclay was described by Prof. J. W. Gregory (18). These concretions are figured by Dr. F. H. Hatch & Dr. R. H. Rastall (19), and appear to be spherulitic in part.

(d) Siderite.—Sir Jethro Teall (20) described a spherulitic siderite found in the Coal Measures of the Midlands, at Fenton-Park Clay-pits, by Dr. Walcot Gibson. Mr. G. W. Lamplugh (22), in his account of the geology of the Zambesi Basin, recorded the occurrence of limonitic spherulites in an indurated clay-rock from the Wankie Coalfield (Rhodesia). The limonitic concretions are hollow, and probably represent a weathered form of spherulitic siderite. In the Fairlight Clays of the Wealden formation, spherulitic siderite-pellets and concretionary nodules are fairly common. I have examined these structures chemically and microscopically. Similar spherulitic structures have also been examined in partly pyritized siderite in an anthracite-seam from South Wales, and in fireclay from the United States. In 1921-23 I also observed that the same form of spherulitic siderite was of fairly common occurrence at certain horizons in the Coal Measures of the Damuda Basin (India). The spherulites occur embedded in the coal in the form of small shot, or as nodular aggregates. The matrix is black and coaly, as in the coaly dolomite spherulites described by Sir Aubrey Strahan.

In addition to the occurrences of spherulitic siderite enumerated above, it is probable that many of the 'sphærosiderite' nodules of the Coal Measures would show this spherulitic structure, if carefully examined. Sections of coal-balls, for example, often exhibit a divergent fibrous arrangement of the carbonate mineral, and siderite-structures in the German Coal Measures (23), which have been erroneously described as plant-species, appear to be spherulitic growths.

(e) Mixed carbonates.—A remarkable example of spherulitic structure in mixed rhombohedral carbonates (mainly of manganese) has recently been found by Mr. A. Broughton Edge at Santo Domingo, Portugal. Scattered through the spherulites are numerous

well-preserved radiolarian casts.

The following tabulated list indicates the localities and approximate horizons from which I have obtained or examined specimens of spherulitic siderite (or altered spherulitic siderite). From the Fairlight Beds and the Indian Coal Measures, numerous samples have been collected and examined: these will be described in detail. From the remaining localities hand-specimens and slides only have been examined: these will be mentioned in the text, and comparisons made as occasion arises.

Locality.

- (1) Fairlight (Sussex).
- (2) Clay-Pits, Fenton Park (Staffordshire).
- (3) Anthracite Collieries, Powell Duffryn (South Wales).
- (4) Wankie (Rhodesia).
- (5) Coalfields of the Damuda Basin (India). Ranegange, Jherria, Karanpura.

Approximate horizon.

Mottled Fairlight Clays and associated sediments, Wealden.

Upper Coal Measures, Etruria Marls and Blackband Group.

Upper Coal Measures.

Upper Wankie Sandstone Series, Gondwana Formation.

Burakur and Ranegange Series, Indian Coal Measures.

II. DESCRIPTION OF SPHERULITES.

(1) The Fairlight Clays.

(a) Field-relations.—I first observed these structures some years ago while examining the Fairlight subdivision of the Wealden formation.

They occur in greatest abundance in the mottled Fairlight Clays, and to a less extent throughout the clays and fine-grained argillaceous sandstones of the Fairlight sequence. They were not observed to occur in beds above the Hastings Sands. The siderite of the Weald Clay, for example, takes the form of fine-grained buff-coloured, clay-ironstone nodules, or of shelly ironstone-beds.

The spherulites occur scattered throughout the mottled clays, either as isolated shot-like individuals measuring about 0.5 mm. to 1 mm. in diameter, or as closely-packed aggregates of these, hardened into compact nodular masses. Where the mottled clays

are exposed to the action of the waves (as on the foreshore a little east of Fairlight Glen), the individual spherulites are washed out of the clay, and collect in hollows in the form of heavy brown sand.

The massive aggregates are left as boulders or nodules, ranging from a few inches to a foot or two in diameter. Where these structures occur in the sandy beds, they are smaller and more irregular in shape than those of the clays. On the exposed portions of the sandstone beach-blocks, they weather out as small brown spots which give to the boulders a freekled appearance.

(b) Megascopic characters.—Both the individual spherulites and the compact aggregate structures bear a close superficial resemblance to oolitic structures, and may easily be mistaken for them. It is interesting to note in this connexion that Drew and Gould, in their sections of the Fairlight sequence published in the Geological Survey Memoir (24), refer to the concretionary beds of the mottled clays as 'courses of pisolitic-looking iron ore', and a similar bed with a sandy matrix which occurs higher in the series is described as a 'hard pinkish oolitic-looking bed'.

The spherulite individuals differ from ordinary colitic structures in their rough pitted exterior, the absence of any tendency to conion structure, the presence of a predominant fibrous radial arrangement, and a characteristic tendency for two or more individuals to coalesce along plane-surfaces of contact. The massive nodular material shows these characters in an aggregate form. When unweathered, the nodules have a density of about 3:3 to 3:5, and are very tough under the hammer. Their colour, which is usually grey or brownish-yellow, appears to be dependent on that of the included clavey matter, since, when found in situ, they have the same colour as the clay in which they occur. Where they are found in the mottled clays, the grey and purple mottling of the clay passes indiscriminately into and across the hard compact nodules, even across individual spherulites, suggesting that the spherulitic growths are later than the mottling in point of time.

(c) Microscopic characters.—The individual spherulites obtained from the mottled clay were found to be too oxidized to yield satisfactory sections. Microscopic examination was therefore confined to the hard compact nodular material, several specimens of which were sliced and examined.

In section, this material shows spherulite individuals and aggregates embedded in a fine-grained, mainly argillaceous

matrix.

The spherulites are seen to be built up of a mass of radiating siderite crystals, which are colourless to faint yellow where fresh and unweathered, but usually stained yellow-brown round the margin of the spherulite, due to slight oxidation. The dark coloration of the outer zone of fig. 2 (Pl. XLII) is due to a slight stain of this nature.

The radiating siderite-crystals may take the form of broad sector-like blades (see Pl. XIII, fig. 1), or of slender fibres, sometimes so fine as to be almost indistinguishable as individuals (see Pl. XIII, fig. 3). Sometimes there is a central area of non-radial granular siderite surrounded by radial fibres. The granular central area usually contains minute scattered inclusions of an opaque non-magnetic mineral, which has been doubtfully referred to pyrites.

In many of the spherulites, the fibrous zone is surrounded by a narrow outer zone of short stout crystals. These crystals do not appear to be in optical continuity with the fibres, but to be set with the optic axis slightly oblique to the radial direction, and neighbouring crystals extinguish alternately as the stage

is rotated.

In all the specimens examined, the radial direction, or direction of elongation of the siderite-blades or fibres, is parallel to the \dot{c} or optic axis of the mineral, since the fibres show greatest relief when their length is perpendicular to the direction of vibration of the polarizer.

This difference in relief produces, with the fibrous varieties, a distinct relief-brush (Pl. XLII, fig. 2a). With crossed nicols, the usual black cross of radial aggregates is seen (Pl. XLII, fig. 2b).

Interference-boundaries .- When the spherulites have had freedom to develop without interference, they are more or less spherical (in section, circular discs) with a mean diameter of 0.6 to 0.9 mm. Where the growth-centres have been too close together to admit of this diameter, the spherulites have interfered one with the other, usually along plane surfaces of contact (straight lines in section). With closely-packed growth-centres, individual spherulites become bounded by plane-surfaces, which are seen in section as polygonal outlines. These polygonal contact-lines show only faint indications of concentration of sediment along them, proving that any sediment present at the time of growth was mainly occluded by the spherulites. The line of contact between two spherulites of different size usually shows a slight curvature towards the smaller individual: that is, the contact-surface is slightly concave towards the smaller spherulite (see Pl. XLII, figs. 2 a & 2 b). This curvature was also observed in sections of spherulites from other localities (see Pl. XLIII. figs. 2 & 5), and indicates a definite law of growth of the spherulites, as will be pointed out later (see § VI, Appendix, p. 693).

Sometimes the surface of contact between two spherulites is represented by a lenticular cavity (Pl. XLII, fig. 1). Into this 'drusy cavity' the small radial scalenohedra of the two spherulites project. The cavity has evidently formed owing to the slower rate of growth of radial fibres near the line joining the spherulitecentres. The supply of solution to these fibres or blades by diffusion would become increasingly difficult as the distance

between them decreased, and eventually impossible as the outer radii (of the surface of contact) met and closed in the space.

Ground-mass.—The sedimentary material in which these structures occur embedded is a fine-grained clayey, or sometimes sandy, mud. Where sand-grains are present in the ground-mass they are also found occluded within the spherulites, indicating that the spherulitic structures are contemporaneous and in place (see Pl. XLII, fig. 3). The sand-grains have mostly a diameter of 0.04 mm. or less. The clayey material is of very fine texture, and polarizes in pale grey of the first order. Under high magnification, individual laths and flakes of a micaceous mineral can be distinguished.

The presence of sand-grains within the spherulites suggests that clayer matter also may be occluded. This is further indicated by the searcity of clavey matter along interference-boundaries, and, although it is not possible to distinguish clay in sections of spherulites by transmitted light (owing to the high refractive index of the siderite), analysis shows that about 10 per cent. of clayey material actually occurs occluded within the siderite.

Method of leaching. - In the various attempts to determine the presence and distribution of this fine detrital matter, the following method was found ultimately to yield the best results. It is described in detail, as it is of fairly general application to cases where it is desired to remove such iron compounds as may mask the structure, or interfere with the examination of sections of sedimentary rocks. A fragment or chip of the material to be examined is thoroughly dried, then heated slowly to a moderate heat in a muffle furnace or over a Bunsen burner, and held at that temperature for a few hours, so as to convert the iron compounds to oxides. If the iron is originally present as oxide, the heating is omitted; if pyrite is present, prolonged heating may be necessary to oxidize and remove the sulphur. The specimen is cooled slowly, boiled in balsam to harden, and sliced in the usual way, care being taken to have the mounting balsam well cooked. The optimum thickness of the ground section is dependent on the material under examination, and can only be determined by trial. For the spherulitic carbonate described above, the best thickness was found to be about twice that of an ordinary rock-section.

The uncovered section is then cleaned free of excess balsam, placed in a shallow porcelain dish, and 'developed' with warm hydrochloric acid (2 parts of acid to 1 of water), to which a few crystals of stannous chloride or fragments of metallic tin

have been added.

The dish is occasionally rocked, and (if necessary) gently heated. With well-cooked balsam, the solution may be heated to 50° or 60° C. without danger of disintegrating the material. When the section has been bleached to a light yellow, it is

removed and washed in distilled water, and thoroughly dried at a gentle heat (30° to 40° C.). If it be desired, the section may be stained at this stage by immersion in a suitable dye, such as eosin or rhodamine, and again dried. A few drops of thin xylol balsam are then placed on one edge of the specimen, and the liquid is allowed to flow slowly into and across the leached material. Any excess balsam is drained off, and the section is warned for several hours to about 30° C., so as to harden the balsam. The specimen may then be covered with a slip containing a drop of xylol balsam, and allowed to remain in a warm place for a few days to set.

Fig. 4 (Pl. XLII) shows a section of a compact spherulitenodule prepared and dyed in this way. The sparsely distributed clayer matter of the leached spherulites, seen in the paler areas, has a radial arrangement, evidently due to the pushing aside of

the clay by the fibres as they grew outwards.

In most of the leached sections of Fairlight spherulites, the central area appears to be almost devoid of clayey matter. From this central area outwards there is a gradual increase in density of the occluded clay to a point marked by the beginning of the outer zone of coarse crystals (see p. 672). The distribution of the clay in this (usually narrow) outer coarsely-crystalline zone is not

nearly so dense as in the fibrous zone which it succeeds.

It would appear that the radiating fibres pushed aside the suspended matter as they grew outwards, the greater part being rearranged radially and occluded within the spherulite. When this ultimately became impossible (on account of the increasing density of the sediment or some such cause) the fibrous habit gave place to a short stumpy crystal-habit which expelled the clay mainly outwards (radially) and only slightly to one side (tangentially), the greater part being excluded by the spherulite. Where the coarse outer zones are absent, the density of the occluded sediment increases outward to the periphery of the spherulite.

Fig. 5 (Pl. XLII) shows a sample of spherulitic hæmatite from the Wankie Coalfield, leached as above, without the preliminary heating. In an ordinary hand-specimen this material would probably be classed as an oolitic hæmatite. The spherulitic character (and probable sideritic origin) is readily seen in a leached

section.

In contrast with these, fig. 1 (Pl. XLIII) shows a pyritic sample of Cleveland oolite, roasted and leached. The siliceous or clayer matter is seen as finely laminated concentric layers, which, when circular, give a black cross with crossed nicols. Elliptical sections show a 'pseudohyperbolic brush'. Consequently, a black cross under crossed nicols cannot be taken as a criterion of radial structure.

Chemical composition .- Samples of individual spherulites

and of fresh argillaceous nodules from the Fairlight Clays were analysed, with the following results:—

Spherulites.		Compact Nodules.	
SiO ₂	Per cent. 6.08 2.54		Per cent. 9.92 6.15
$egin{aligned} & \operatorname{Al}_2 O_3 & & & & \\ & \operatorname{Fe}_2 O_3 & & & & \\ & \operatorname{FeO} & & & & \\ & \operatorname{MnO} & & & & \end{aligned}$	18·10 42·82 0·08		1.04 48.63 0.15
CaO MgO CO ₂	0·50 0·45 26·88		0.55 0.66
$H_2\tilde{O}$ and organic matter Totals			2·35 100·42
Clayey matter insoluble in hydrochloric acid. Ignited.	8·76 per	· cent 16·64	per cent.
P	roximate	Analyses.	
Clay Ferric oxide Ferrous carbonate Calcium carbonate Magnesium carbonate	18·10 69·00 0·90		Per cent. 18:90 1:04 78:5 1:0 1:2
Totals	99.00	•	100.64

The chief difference in composition between the two specimens is a larger proportion of sediment in the compact nodule, due to the additional clayey matter between the individual spherulites. The siderite of the nodule is fresher, and has suffered less oxidation than that of the individual grains.

In both cases the lime is much lower than the average for ironstone of the Weald Clay, which usually contains 3 per cent. or

more of calcium carbonate.

(2) Upper Coal Measures of the Midlands.

A specimen of spherulitic ironstone, obtained by Dr. Walcot Gibson from the Fenton Park Clay-pits, is mentioned in the Summary of Progress of the Geological Survey for 1898, by Sir Jethro Teall (20). The rock is described as being

'composed almost entirely of spherulites of siderite. The spherulites measure from 1 to 1.5 mm. in diameter, and are usually composed of eight or ten individual crystals. They are often stained brown at their margins, in consequence of the decomposition of the siderite and the oxidation of the iron. Sometimes the spherulites are in close contact with each other, and sometimes there is a small quantity of brown interstitial matter. The insoluble residue consists of a very fine mud. The rock is a spherosiderite.'

An analysis of this rock by Dr. W. Pollard is given, and is reproduced here, with the calculated proximate analysis, for comparison with the Fairlight spherulites.

Analysis.		Proximate Compositio	n.
F	er cent.		Per cent.
FeO		Clay and organic matter	. 15.25
T- 0		Ferric oxide	
Fe ₂ O ₃	1.56	Ferrous carbonate	
Al ₂ O ₃	0.24	Manganous oxide	
P ₂ O ₅	0.00	Calcium carbonate	
MnO		Magnesium carbonate	
NiO CoO	trace	Magnesium carbonate	. 110
CoO	0.05	matal.	08:50
CaO		Total	, 30 00
MgO	1.36		-
$\widetilde{\mathrm{CO}_2}$	31.87		
S	trace		
Organic matter	0.47		
Ignition	11.68 (re	esidue)	
Water at 105°	0.23		
Water of ignition	1.20		
Total	99.76		
		D	
		Per cent.	
Ignited res	idue : SiO	7.22	
		Ō ₃ 4·00	
	Fe_2	O ₃ 0.41	
		Total 11.63	

The composition of the rock is very similar to that of the Fairlight nodule.

By the courtesy of Mr. G. W. Lamplugh and Dr. Herbert H. Thomas, I was permitted to examine the Geological Survey specimen and section. The structures closely resemble the bladed variety of spherulites common in the Fairlight Clays. The individual spherulites are slightly larger, however, than those of the latter, and the blades are broader and more pronounced.

According to Dr. W. Gibson (21), these structures are fairly common in the Upper Coal Measures of the Midlands. The Etruria Marls sometimes contain them in such quantity as to

render the clay useless for the manufacture of pottery.

A sample of clay-with-concretions which I obtained from these beds shows small spherulite-shot, about 1 mm. in diameter, scattered through a grey clay, very similar to the grey clay-with-concretions of the Fairlight Beds. The clean spherulite-shot yielded the following proximate analysis:—

Pe	er cent.
FeCO ₃	83.5
CaCO ₃	
MgCO ₃	0.6
Ignited clayey matter	13.4
Water (by difference)	
_	
Total	F00-0

(3) South Wales Coalfield.

The occurrence of spherulitic structures in association with pyrites, in 'coal brasses' from the Powell Duffryn Anthracite

Collieries was brought to my notice by Prof. C. G. Cullis.

The spherulites occur embedded in a coaly matrix, and consist mainly of pyrite. A slice from a less pyritic or more 'stony' sample was found to contain numerous spherulites of siderite (yellow), with some calcite or dolomite (colourless). The coaly matrix is traversed by numerous shrinkage- or pressure-cracks, which sometimes pass into the spherulites. These secondary cracks are mostly filled with colourless carbonate.

There is little doubt that the spherulitic portion of these 'coalbrasses' represents a crushed and partly pyritized spherulitic Similar pyritization has been observed in spherulites from Indian coals (see p. 678), as also the deposition of secondary mineral (calcium phosphate) in shrinkage-cracks in the coaly

matrix.

An analysis (approximate only) of the 'stony' sample is given below, together with the calculated proximate analysis.

Analysis.	Proximate Composition.
Per o	ent. Per cent.
SiO ₂ 2·0	2 Organic matter 17.37
Al ₂ O ₂ 1.5	'0 Clayey matter 5.30
Fe,O ₃ 1.6	
FeO 28.3	36 Siderite 45.60
MnO 0.1	5 Calcium carbonate 10.80
CaO 6-2	5 Magnesium carbonate 9.66
MgO 4.6	Calcium phosphate 0.40
P.O 0.2	00
FeS ₂ 10.5	0 Total 99.63
CO ₂ (calculated) 26.9	0
Moisture 0.5	35
Organic matter (difference). 17:3	57
	_
Total 100.0	00

It will be observed that the calcium and magnesium carbonates are present in approximately dolomitic proportions, a relation which holds for most of the sideritic spherulites examined.

(4) Wankie Coalfield (Rhodesia).

In his description of the geology of the Zambesi Basin, Mr. Lamplugh records the occurrence of spherulitic limonite in some

of the indurated clays of the Wankie Coalfield (22).

A sample of this material, in the Geological Survey collection, shows individual spherulites of limonite, about 1 mm. in diameter, scattered through a clayey rock. Some of these spherulites, when fractured, are seen to be hollow, with delicate radial partitions. There is little doubt that this material represents an altered spherulitic siderite, oxidized and partly leached.

A specimen of concretionary hæmatite-rock from the Upper Wankie Sandstone (25), kindly supplied to me by Mr. H. B. Maufe, Director of the Rhodesian Geological Survey, has also been examined. The hand-specimen shows a dense mass of small hæmatite-concretions which might easily be mistaken for oolitic structures. When the rock is sliced and leached, the matrix is seen to consist of a fine-grained sandy clay with radiating or spherulitic structure (see Pl. XLII, fig. 5). The rock is an altered spherulitic siderite.

(5) Indian Coal Measures.

Spherulitic siderite occurs at a number of horizons in the coalfields of the Damuda Basin, and forms a considerable proportion of the stony tip-refuse from some of the collieries in the Ranegange and Jherria fields.

Samples collected by me from the following localities have been sliced and examined:—

(i) Nakari Nala, South Karanpura Field.

The outcrop of coal-horizon 36, in the Nakari stream, contains abundant spherulites scattered through the coal as individual grains and as nodular masses. The individual grains occur mainly in the bright portions of the seam, and measure 2 to 3 mm. in diameter. They have become oxidized and partly leached by weathering, and the outer portions of the nodular masses have suffered in the same way. The fresh inner portions of these nodules present a brownish-black stony appearance, with a granular fracture recalling that of the compact Fairlight nodules. Small stringers and blebs of pyrite are fairly common. The density of

the compact material is about 3.15.

Microscopic characters.—In thin sections this material shows excellent spherulitic structures of siderite embedded in a coaly matrix. The spherulites are fibrous, and give a distinct black cross between crossed nicols. The colour in ordinary light is yellowish-brown, owing to the presence of finely-divided organic matter. The segregation of this organic matter at intervals during growth has produced an appearance of 'concentric zoning' in some of the spherulites. In addition to this 'zoning' of the suspended sedimentary material, there is a 'patchiness' running irregularly across many of the spherulites (see Pl. XLIII, fig. 2) which suggests that the distended organic sediment varied irregularly in density and composition from point to point within the area of a spherulite. This difference in density was not sufficient to interfere with the outward growth of the crystal-fibres, since they pass through these darker patches without interruption.

A notable feature of these and similar coaly spherulites is the tendency of the radiating fibres to curve or sweep round towards certain points. In section, this curvature appears to be away from

adjacent spherulites and towards cavities or coaly areas devoid of carbonate. This suggests that the cavities or coaly areas represent channels along which the carbonate 'food-supply' was diffused. The radii are sometimes elongated towards these areas, causing a corresponding distortion of the spherulite.

Irregular veins and patches of pyrites are seen in some sections. The secondary origin of this pyrites is proved by the manner in which it cuts into and across spherulites, while still retaining the structure of the replaced portion of the spherulite. Junctions between interfering individuals are usually straight, as in the Fairlight spherulites. Sometimes the surface (or contact-line in section) is slightly concave towards the smaller spherulite. The junctions are almost free from 'sediment-lines', indicating (as before) only slight outward expulsion of the sediment during growth.

Carbonaceous matrix.—The dark hue of this occluded carbonaceous material renders its distribution within the spherulites more or less evident in sections, especially when strongly illuminated, or when seen by reflected light. It can best be examined, however, by leaching away the iron carbonate. Fig. 2 (Pl. XLIII) shows a leached section of this material, prepared by allowing the uncovered section to stand for several days in cold dilute hydrochloric acid containing a little stannous chloride, the object being to remove the carbonate without effervescence or oxidation. As a test of complete removal of iron, the section was finally warmed in strong hydrochloric acid, then washed, dried, and mounted in the manner described on p. 674.

The section shows the distribution of the occluded sediment in perfect detail. As in the case of the argillaceous spherulites, the siderite-crystals have impressed their radial outlines on the fine-grained sediment by a partial expulsion towards the boundaries of the individual crystals. The radial areas formerly occupied by siderite, and bounded by dark lines of organic sediment, contain a

brownish-vellow amorphous substance.

The 'zoned' appearance of some of these spherulites in ordinary sections is seen in this leached slide to result from a periodic concentration of the organic matter of finer texture in rings or 'shells' about the centre. These 'zones' were observed in most of the coaly specimens examined, and appear to bear some relation to the state of subdivision of the matrix or sediment.

In some portions of the section (mainly in areas free from spherulites) traces of vegetable tissue and cell-structure can be

made out.

Chemical composition.—The composition of one of these Karanpura nodules is shown on the next page:—

Analysis.		Proximate Composition.	
I	Per cent.	Pe	er cent.
SiO.,	0.22	Organic matter (by difference)	7.0
Al,Ô ₃	0.39	Siderite	
Fe,O ₃	6.82	Calcium carbonate	
FeO	48.70	Magnesium carbonate	
MnO	0.05	Calcium phosphate	
CaO	1.95	Ferric oxide	
MgO	1.60	Clay	0.7
P ₂ O ₅		-	
CO ₂ (calculated)	32.92	Total	100.0
Moisture		*	
Insoluble in acid	6.31		
Total	99.44		

The rock is a blackband siderite containing about 7 per cent. of coaly matter and 6 per cent. of dolomite.

(ii) Lower Thick Seam, South Karanpura Field.

In one of the boring cores from this 60-foot seam small sideriteshot was found scattered through the bright part of the coal, the dull or 'bone' coal being almost free from concretions. The spherulites have an average diameter of about 0.7 mm., and the siderite of the outer layer has been partly leached away. This leaching has not been brought about by the action of the washwater from the boring, since the concretions also show the same 'weathered' appearance in the fresh coal of the fractured core. The depth of the seam below the surface at this point was approximately 150 to 200 feet.

(iii) Loyabad Colliery, Jherria Field.

Many big boulders showing spherulitic structure occur in the tip-refuse from this colliery, often with an adhering outer shell of bright coal. A sample from one of these nodules, with the attached bright coal, was taken for examination. The stony portion is a hard, dense, brownish-black rock similar to the Karanpura material, except that the texture is finer, owing to the smaller spherulitic structure.

Microscopic characters.—Fig. 3 (Pl. XLIII) shows the appearance of a section of this rock. The spherulites are small, uniform in size, and closely packed. Their diameter is about 0.7 mm. The siderite is of the fibrous variety, tending to bladed structure. The colour is yellow-brown, owing to occluded organic matter. Indications of the same periodic 'zoning' of the occluded sediment as that seen in the Karanpura material are present in most spherulites.

The dense interstitial coaly matter between the spherulites is broken up by numerous shrinkage-cracks, which have developed subsequently to the growth of the spherulites. These cracks have

been filled in with calcium phosphate, which mineral also occurs in cracks and cavities of the outer zones of the spherulites.

Chemical composition.—Chemical and proximate analyses of this rock are tabulated below:—

Analysis.		$Proximate\ Composition.$	
1	Per cent.	P	er cent.
SiO.,	0.69	Coaly matter (by difference).	8.0
Al ₂ Ô ₃		Siderite	75.0
Fe,O3		Calcium carbonate	2.5
FeO.		Magnesium carbonate	.3.8
MnO	0.06	Calcium phosphate	6.3
CaO	4.80	Ferric oxide	2.8
MgO		Clay	1.5
P.O			
CÔ ₂ (calculated)		Total	99.9
Moisture		=	
Insoluble in acid	6.35		
Total	98.56		

Except for the secondary calcium phosphate present in this material, the composition compares closely with that of the Karanpura spherulitic rock.

Coaly matter.—An examination of the coaly matter present within the Jherria and Karanpura nodules, and of the coaly layer outside the Jherria nodule, gave the following results:—

	Volatile Matter.	Fixed Carbon.	Ash.	Nature of Carbon.
Jherria: nodule crushed. Treated with hydrochloric acid. Coal- residue collected, washed, dried and tested.		75.5	2.9 {	Sooty. Non-coking.
Jherria: coaly layer on the out side of the nodule. Powdered and digested with hydrochloric acid. Washed dried, and tested	21 0	74:3	4.7 {	Strongly coking. Much intumes- cence.
Karanpura: nodule crushed treated with hydrochloric acid and residue collected, washed dried, and tested.	27.5	70.2	2.3 {	Sooty. Non-coking.

This non-coking property of the occluded coaly matter was characteristic of all the coaly nodules examined, most of which were obtained from coking seams. The difference is not due to acid treatment, since all the above-mentioned samples were subjected to the same digestion with acid. The non-coking property appears to be inherent in the material, and due in some way to its association with the siderite.

This difference in behaviour is also illustrated by the following

extraction tests :-

One gram of the coaly matrix obtained by solution of a Jherria nodule in hydrochloric acid, and one gram of the bright coal residue treated in the same manner, were extracted with pyridine, until the extract became clear, the material being filtered through a Gooch crucible, collected, and evaporated.

	Per cent. extract.	Appearance of extract.	Result on heating.
1 gm. coaly matrix of nodule.	} 3.92	$\left\{ \begin{array}{l} \text{Brownish black.} \\ \text{Tarry appearance.} \end{array} \right.$	Swelled up to a soft coke.
1 gm. bright coal outside nodule.	9.76	Tarry appearance.	Swelled up to a soft coke.

(iv) Gurundih Colliery, Ranegange Field.

A hand-specimen derived from this colliery showed irregular

spherulites loosely held in a coaly matrix.

In section this material is dark red, even in the thinnest slices. The spherulites are irregular, and tend to become oval along the direction of bedding. The radiate arrangement of the siderite is almost subordinate in places to the zoned structure of the matrix. Towards the outer part of the spherulite the radial arrangement becomes more prominent; but the crystals show a tendency to curve round towards the direction of bedding, and to become disturbed by elongation in that direction.

These structures have evidently grown with difficulty in a coaly matrix of greater density than the Jherria or Karanpura sphe-

rulites.

Since the above was written, I have discovered similar spherulitic structures in an American fireclay, obtained at Harbison & Walker's Works, Pittsburgh (Pennsylvania). On being separated, the 'pimply' concretions proved to have the following chemical composition:—

Analysis.		Proximate Composition	/
U	1·80 0·21 0·11 8·10 29·07	_	Per cent 88.74 . 0.37 . 0.23 . 11.15

The concretions thus correspond closely in composition with those of the Fairlight Clay. They have a maximum diameter of about 0.5 mm., and consist of aggregates of stumpy siderite-crystals with a tendency to radiating structure towards the outside of the concretion. The crystals show greatest relief when the direction of vibration of the polarizer is perpendicular to their length.

III. SPHERULITES WITH RADIOLARIA IN RHOMBOHEDRAL CARBONATES, SANTO DOMINGO (PORTUGAL).

This interesting rock was discovered by Mr. A. Broughton Edge, in a boring at Santo Domingo. The carbonate-rock was encountered as a 4-inch band, while the bore was passing through a thick zone of blue slate.

A fragment of the 1.5-inch diameter core kindly supplied to me by Mr. Edge shows, in one portion, a pale-grey carbonate rock which shades off into a dark-blue grey material. Both portions show small ill-defined concretions measuring about 1 mm. in diameter. In the grey rock these pellets have the same grey coloration as the rock; in the dark portion they are reddish brown. A few small veins of quartz traverse the specimen.

Microscopic characters (grey portion).—A slice taken across the grey material shows colourless crystalline carbonate, containing numerous radiolarian remains (see Pl. XLIII, fig. 4).

In addition to the radiolaria (maximum diameter about 0.18 mm.) the carbonate shows a number of larger 'zones' or annular rings (diameter=about 0.7 mm. and thickness =0.1 mm.). These 'zones' are darker in appearance than the surrounding carbonate, due to the aggregation within them of numerous minute inclusions. Sometimes two or more such zones occur, concentric and near together, and sometimes two adjacent zones have met and become truncated at their points of intersection (see Pl. XLIII, fig. 5). Under crossed nicols the whole of the crystalline carbonate exhibits spherulitic structure.

In some cases crystallization has commenced about a radiolarian cast, but this does not appear to have been general, for the greater number of the radiolarian remains occur scattered indiscriminately through the spherulites, and do not appear to have interfered with the radial growth in the least. Fig. 4b (Pl. XLIII) shows the appearance of the material under crossed nicols. Towards the centre of the spherulites the crystal-fibres are extremely fine, and hardly visible as individuals even under high magnification. Farther out (usually beyond the zonal 'shell') the radial structure tends to become bladed or columnar, with undulatory radial extinction.

In polarized light, a faint 'relief-brush' is discernible, with the axis of greatest relief perpendicular to the direction of vibration of the nicol. The fibres are, therefore, elongated along the \dot{c} axis, as in the sideritic spherulites. When the junction between adjacent spherulites is clearly visible, it approximates to a straight line (with local irregularities) corresponding to a plane surface in the solid.

The quartz-veinlets which traverse the rock-specimen are seen in section to be secondary infillings of cracks or fissures formed subsequent to the spherulitic growth. If a vein cuts a zoned spherulite, the effect is one of fracture and separation, and not of

partial obliteration of the zone. The two separated portions of the zone circle are entire, and would fit if brought together.

Chemical composition.—A small quantity only of this material was available for chemical analysis, and the following results are merely approximate, but probably correct to the nearest 1 per cent.

	Proximate Composition	n.
er cent.]	Per cent.
10.4	Silica	10.4
3.6	Alumina	3.6
15.4	Iron carbonate	$22 \cdot 2$
32.3	Magnesium carbonate	1.9
0.9	Calcium carbonate	15.2
8.6	Manganese carbonate	47.0
0.1	Calcium phosphate	0.2
0.3	Moistare	0.3
29.4		
	Total	100.8
101.0		
	10·4 3·6 15·4 32·3 0·9 8·6 0·1 0·3 29·4	2er cent. 10.4 Silica 10.4 3.6 Alumina 15.4 Iron carbonate 32.3 Magnesium carbonate 0.9 Calcium carbonate 0.0 Calcium carbonate 0.0 <t< td=""></t<>

The iron and manganese have been estimated as sesquioxides and calculated back to carbonates, in which form they are present in the rock.

Blue portion.—A section across the blue-grey material shows remnants of spherulitic structure stained brown and surrounded by patches of calcium phosphate, in the form of aggregates of minute laths polarizing in grey tints.

The radiolarian casts are partly destroyed, and most of the

carbonate mineral has disappeared.

The material possesses the following approximate composition:—

Analysis.		Proximate Composition	/ e
P	er cent.	P	er cent.
SiO.,	19.5	Silica	19.5
Al,\tilde{O}_3	10.6	Alumina	10.6
Fe,O ₃	14.7	Iron carbonate	21.4
Mn_2O_3	6.5	Manganese carbonate	9.4
MgÔ "	0.5	Magnesium carbonate	1.1
CaO	20.3	Calcium carbonate	8.7
P.,O ₅	13.1	Calcium phosphate	28.6
Loss on ignition	12.6		
		Total	99.3
Total	97.8	÷	

IV. ORIGIN OF THESE STRUCTURES.

(a) Characters in common.—If we compare these various occurrences of spherulitic siderite, we observe that they possess a number of features in common. These features, as enumerated on the next page, enable us to deduce certain facts as to the mode of origin of the structures.

(1) The spherulites all occur in association with fine-grained

sediments of the mud or silt type.

(2) These sediments consist almost entirely of comminuted plant-tissue, or of clay (sometimes of fine sandy clay); and even in the latter case the sediments contain vegetable matter.

(3) The deposits seem, without exception, to be of freshwater

origin, and appear to be devoid of calcareous shelly remains.

(4) The carbonate mineral consists of nearly pure siderite, with a little carbonate of lime and magnesia, these two being present

usually in dolomite-proportions (CaCO₃MgCO₃).

(5) The spherulites are fairly uniform in size locally, with a tendency to be less regular and somewhat smaller in the sandy sediments. The smallest spherulites are about 0.5 mm. in diameter, and the largest spherulites observed attain a diameter of 2 to 3 mm. The internal structure is prominently radial, with some zoning of the included sediment.

(6) The structures contain occluded sediment of type similar to that in which they are embedded. They are strictly authigenic,

and have included this sediment during growth.

(7) Interfering surfaces between adjacent spherulites are mostly planes, but occasionally are slightly-curved surfaces concave towards the smaller individual. These surfaces generally are fairly free from sediment, indicating that the sediment-medium in which these structures grew was almost totally occluded, with only slight expulsion outwards.

(8) Where the spherulites show zoning of the sediment, the zoning is subordinate to radial structure, and the zones become abruptly truncated at the points of contact with adjacent interfering spherulites. Indications of serious interruptions of growth such as fresh enveloping spherulites, or the banded stromatoliths

of Kalkowsky, etc., are absent.

It is evident from the foregoing facts that the formation of these siderite structures has depended in some manner on the clavey or fine-grained nature of the sediments, the presence of carbonaceous matter, and probably the absence of shelly carbonate of lime.

The spherulites have formed from iron-carbonate solutions held within the gradually-settling and consolidating sediment: the carbonate was not precipitated chemically from solution, or, if it was, it became redissolved within the sediment, and finally crystallized out in a spherulitic form.

(b) Source of the iron-carbonate solution.—It is a well-known fact that decaying vegetation exerts a powerful solvent action on iron-bearing compounds in the soil and subsoil, as may be seen by the bleached character of many subsoils underlying peaty beds and the common occurrence of beds of white sand in association with plant-bearing sediments. River-waters containing vegetable matter usually carry more iron than those free from vegetation. E. S. Moore reported 47 to 61 parts of iron

peroxide per million in rivers feeding lakes where iron-ores were being formed, and the waters all contained organic matter. These figures are in strong contrast with the average of less than 1 part

per million for ordinary river-waters.

In 1910, F. Weiss (26) showed that peat-solutions would change an impure clay residue to an almost pure kaolin, and Sven Odén (27) formed the opinion that humates of ferrous and ferrie iron exist, and that in Nature they are probably colloidal and retain iron persistently. J. W. Gruner (28) has recently studied the action of peaty solutions on rocks of various types. results show that varying quantities of silica (25 to 160 parts per million) and of iron (9 to 90 parts per million) are dissolved, the amount depending on the type of rock and on other constituents present, such as calcium carbonate and magnesium carbonate, which may exert a neutralizing effect on the peat-acids and so prevent solution. Gruner notes that iron is partly present as 'ions' and partly in the colloidal state, and is always in the ferrous condition. 'The addition of 'salt' solutions increased the acidity and the solubility effect, except where these salts were the carbonates of lime and magnesia. Carbonate of lime exerts a pronounced retarding effect on the solubility of iron compounds, possibly owing to the removal of carbon dioxide. The solvent action for iron compounds of these peaty solutions may be merely that of carbon-dioxide water, the organic matter acting as a reducing and protecting medium. In the absence of calcium carbonate, the iron taken into solution varied from about 20 to 90 parts per million. In the presence of carbonate of lime, the iron amounted to only 8 or 9 parts per million, and this amount remained in solution after aëration and precipitation tests, from which it may be inferred that this iron exists in the colloidal form, possibly combined with the organic matter.

(c) Deposition of the siderite.—If we postulate such highly ferruginous rivers or streams carrying fine sediment rich in vegetable remains into shallow freshwater lakes, the question arises: In what manner could the iron-carbonate solution become concentrated within the settling sediment to such a degree as to give rise to the radial crystalline form of the mineral? In the formation of clay-ironstone and 'blackband' deposits, E. C. Harder and other observers have assumed that the iron carbonate is precipitated directly into solution by loss of carbon dioxide, either by diffusion into the air, or by the action of living plants.

A serious objection to either of these assumptions is that the conditions under which precipitation is assumed to occur are not very different from those under which solution of the iron is generally believed to have taken place. For any iron to be held in the ferrous condition, carbonaceous matter must be present, and this implies that oxidation of a portion of the carbonaceous matter to carbon dioxide is continuous, as is also indicated by the evolution of the excess gas from stagnant pools, etc. E. C. Harder (29) has

shown that a number of iron-depositing bacteria exist, but these are only effective in causing the precipitation of iron as ferric hydrate by oxidation of ferrous compounds. Precipitation in the form of ferrous carbonate by such bacteria has not been observed.

The experiments of J. W. Gruner have shown that undissolved carbonate of lime may, by removing excess carbon dioxide, exert a powerful precipitating action on natural solutions of iron salts; and the deposition of iron carbonate, in the form of clay-ironstone beds and nodules (usually rich in shelly remains) has undoubtedly been brought about largely by the concomitant solution of a portion of the associated shelly matter. This agency, however, could not account for the formation of the spherulitic clay-ironstones. These deposits show a consistently low lime-content, and shelly remains appear to be absent from them. Moreover, the spherulitic structure developed indicates crystallization rather than chemical precipitation.

I suggest, as the most satisfactory explanation of the concentration and deposition of the iron carbonate in these cases, that the iron compounds present in solution as soluble carbonates, humates, or hydrolized and possibly colloidal hydrates, were absorbed by the fine-grained and partly colloidal sediments, and

carried down with them during deposition.

Recent studies in adsorption-phenomenon have shown that substances possessing a large specific surface, such as highly porous bodies and gels, form the best adsorbents, and that substances of high molecular weight, or in the colloidal state, are most strongly adsorbed. Examples of this phenomenon are (1) the fixing of a dye in a mineral gel or a clay by the staining process, (2) the bleaching of coloured organic solutions by animal or sugar charcoal. Assuming such an adsorption of a part of the dissolved iron-compounds by the semicolloidal sediments, conditions of supersaturation would automatically result from the settling and flocculation of the sediment and the gradual upward expulsion of the more readily diffused water-molecules. Crystallization would then commence at a number of centres simultaneously, and continue pari passu with the removal of the water from the sediment.

The maximum concentrations of iron-solutions obtained by Gruner were of the order of 100 parts per million. Concentrations considerably above this figure might be possible with solutions brought gradually to a maximum state of supersaturation by the process outlined above, but the concentration would in all probability still be of a very low order: that is, the solutions would be predominantly aqueous. Hence the iron carbonate for the growing spherulites would be derived in a great measure from the surrounding clayey medium by diffusion. The 'food-supply' would not be all 'on the premises'—as is the case, for example, with most

artificial spherulites and spherulites of igneous origin.

Q. J. G. S. No. 324.

With relatively slow diffusion, through a highly gelatinous medium, crystallization would be limited by the rate of diffusion,

and conditions would exist favourable to the production of 'zoned' structures. Some of the strongly-zoned spherulites from the Ranegange Coalfield (see p. 682) appear to have grown under

these conditions in a very gelatinous medium.

With relatively rapid diffusion through a flocculated or only slightly gelatinous sediment, crystallization would not be limited by the rate of diffusion, and there would be a minimum tendency to zoning. Most of the spherulites of iron carbonate appear to have formed under these conditions.

If we consider the case of a spherulite growing in a clayey medium, and occluding all the distended sediment lying within its own volume, the outward growth-relative to that of an adjacent spherulite-would be uniform, however the conditions within the surrounding medium were changed, and it would follow (see pp. 697-701, Appendix) that the surface of contact between the two adjacent spherulites of unequal size would be a hyperboloid concave towards the smaller individual, and of a curvature controlled exclusively by the position of the first point of contact of the spherulites relative to the two centres.

If, however, the distended sediment were partly expelled radially, so that diffusion (and hence the outward growth) became impeded more and more as the diameter increased, the smaller spherulite would have the advantage, and the contact-surface would become With sufficient retardation less concave than the true hyperboloid. the contact-surface would become convex towards the smaller

spherulite (see p. 702, Appendix).

The presence of a faint sediment-line along many of the spherulite-junctions (best observed in leached sections) suggests a slight outward expulsion of sediment, and the relatively flat curvature of the contact-line between spherulites of unequal size (see Pl. XLII, figs. 2, 4, & 5) indicates a retardation of outward growth as the diameter increased. It may be that this retardation has been the principal agency in limiting the size of these structures.

If adsorption of the iron-solutions by the suspended sediment has brought about concentration of the iron-compounds in the manner indicated above, it would be expected that fine-grained or highly-distended sediments would absorb a higher proportion of the solutions, and so contain (when consolidated) more iron car-

bonate than the coarser sediments.

This conclusion is strikingly illustrated by the distribution of spherulites in the Karanpura thick coal-seam mentioned on p. 680. The spherulites are practically confined to the bright layers of the coal, the dull bands being almost barren. The bright coal contains about 3 to 4 per cent. of ash, and has probably been derived from a semicolloidal organic sediment. The dull coal contains 20 to 35 per cent. of ash, and represents a coarser coaly-clay sediment.

Similarly with the Fairlight Beds, it was observed that the sandy sediments were markedly spherulitic only near the junction of these beds with the overlying spherulitic clays—a strong indication that the iron-solutions were originally collected in the finer-

grained or clayey sediments.

The mixed-carbonate spherulites found by Mr. A. Broughton Edge, and described on p. 683, may also have resulted from a similar concentration of manganese, iron, and calcium solutions in the radiolarian sediments and surrounding clay (now blue slate). The uncrushed character of the radiolarian casts, the secondary infilling of cracks in the spherulites by silica, and the partial destruction of spherulites and radiolaria by secondary calcium phosphate, all suggest that these spherulites were formed before a complete consolidation of the sediments.

(d) Occluded sediment: artificial spherulites.—In order to observe the behaviour of a distended sediment towards a growing spherulite, supersaturated solutions of salicin containing (1) flocculated clay, (2) bentonite, and (3) a gelatine-gel were allowed to crystallize in test-tubes. In each case perfect spherulites were formed, the sediment being completely occluded. The contact-surfaces between interfering spherulites were free from sediment, and the structures showed no zoning unless crystallization was temporarily checked by arresting the cooling process.

When these crystallizations were carried out on glass plates under the microscope, very similar results were obtained; the crystallites were observed to grow rapidly outwards and around any suspended particles, without attempting to orient or move the particles in any way. Zoning was not prominent. If, however, the conditions were so arranged that the gelatine-film became extremely viscous before crystallization commenced, the rate of crystallization became very much reduced, and the minute crystallites showed a beautiful zoned arrangement under crossed nicols, similar to the cholesterin crystallites described below.

It would appear from these results that rapid spherulitic crystallizations do not produce zoning, or cause any ordered

arrangement of solid matter suspended within the medium.

The observation of H. Schade that spherulites only show zoning when the medium contains other substances than the one crystallizing out in spherulitic form, does not appear to hold for every case. Pure cholesterin gives beautifully-zoned spherulites when a thin film of the molten substance lying between a glass slip and cover-glass is rapidly cooled. If the cooling is carried out on the microscope-stage between crossed nicols, crystallization is seen to commence at a few points, and grow rapidly outwards without zoning. Then, owing apparently to a change in the viscosity of the medium, crystallization becomes slower, and zoning takes place. Spherulites which formed subsequently to the change in viscosity mentioned above are zoned from near the centre.

Relation to Clay-Ironstone.

Clay-ironstone is generally regarded as a precipitate-deposit; its fine-grained texture and tendency to form around organic remains

support this view.

It has been pointed out on p. 675 that the Wealden Clay ironstone (which usually occurs associated with shelly remains) contains 3 per cent. or more of calcium carbonate. The spherulitic carbonate and associated sediments of the mottled clays appear to be devoid of shelly remains, and the spherulites are low in calcium carbonate—a feature common to all the siderite spherulites examined.

If we assume that the precipitation of this clay-ironstone has been brought about by the concomitant solution of detrital or comminuted shelly matter, the relation of the two forms of siderite becomes clear. The clay-ironstone is a precipitate formed in accordance with the equation Fe(HCO₃)₂+CaCO₃=FeCO₃+Ca (HCO3), and the spherulitic carbonate represents a direct crystallization from supersaturated solution in the absence of such a precipitant. This view is supported by the relative grain-size of the crystals of the two forms of siderite, as shown below.

Material and Locality. Clayband, Coal Measures, Staffordshire.	Mean Grain-size. mm. 0.01	Remarks. A characteristic 'jump' from aggregates to individuals. The latter are fairly uniform in size.
Clayband, Coal Measures, Lancashire.	0.01 to 0.015	Do.
Clayband, Wealden, Crowhurst, Hastings.	0.005 to 0.01	Do.
Clayband, Wealden, Quarry Hill, Tonbridge.	0.015 to 0.02	Some shell-fragments, with included rhombs and scalenohedra of siderite, 0.015 mm.
Clayband, Wealden, Telham Hill, Battle.	0.005 to 0.01	A characteristic 'jump' from aggregates to individuals.
Siderite spherulites (individuals), Fairlight.	0.13 downwards	Crystal-fragments grading downwards, without the characteristic
Siderite spherulites, compact nodule, Fairlight.	0·1 downwards	'jump' recorded above.

Where the clay-ironstone occurs scattered through the clays as nodules containing shelly remains, it may be that the iron-solutions first became concentrated by adsorption in the clay, and that precipitation then took place around shelly matter included within Regions of low concentration for iron-solutions the sediment. would thus be produced, towards which more iron would suffuse and become precipitated in turn. Such an origin would explain many features of these nodules, including (a) their concretionary formation about shelly remains, with a tendency to elongation along the direction of the bedding; and (b) the common presence in these nodules of septarian cracks containing secondary calcite. dolomite, or some mineral other than siderite.

Comparison with Oolitic Ironstone.

'In the Summary of Progress of the Geological Survey for 1922, it] was pointed out that the green silicate of iron (chamosite), which is a prominent constituent of the Cleveland, Frodingham, and other similar bedded onlitic carbonate-ores, appears to be absent from the Coal Measure clay-ironstones. This absence of chamosite from the clay-ironstones is attributed to the 'stronger conditions of carbonation' which obtained during their formation.

In the latter group might also be included the Wealden clayironstones and the various spherulitic siderites that I have examined, in none of which was any trace of iron-silicate mineral observed.

Whatever be the cause of this difference in mineral composition, it would appear that the absence of green silicate-mineral has been essential to the formation of the spherulitic form of siderite, and its presence necessary for the development of the oolitic

variety.

The presence of colloidal silica and silicates within the consolidating sediments would render them highly gelatinous and resistant to ready diffusion of solutions. These conditions, as we have seen, would favour the production of zoned or banded structures. Very slow diffusion would also result in a considerable proportion of the iron remaining disseminated through the sediment, that is, not segregated. This is a characteristic feature of the oolitic carbonate-ores which grade imperceptibly from iron-ores into unprofitable sediments.

In the clay-ironstones (and to a much more striking extent in the spherulitic variety) segregation has been more complete. If a fragment of compact spherulitic carbonate be ignited for some time and then examined, the clayey matter between the individual spherulites is seen to be creamy white, and proves on analysis to contain less than 2 per cent. of iron. Fragments of Cleveland or Frodingham ores when ignited become uniformly red throughout, even when the total amount of sediment present is much higher than in the compact spherulite-rock.

In conclusion, I desire to express my thanks to Prof. W. W. Watts and to Prof. C. Gilbert Cullis for their help at the Imperial College of Science & Technology, where the earlier part of the work on the Fairlight Clay spherulites was carried out; also to Prof. P. G. H. Boswell for his kind help and criticism while the greater part of the above work was being conducted under his direction at the University of Liverpool, and for his trouble in seeing this paper through the press.

I am further indebted to Mr. A. Broughton Edge for kindly supplying the samples of the radiolarian spherulitic rock for examination and comparison; to Mr. H. B. Maufe, Director of the Rhodesian Geological Survey, for forwarding samples of spherulitic hæmatite from the Wankie Coalfield; and to Messrs.

Bird & Co., Calcutta, for permission to publish analyses and other information appertaining to spherulites from the Karanpura and Jherria coal-seams.

V. REFERENCES.

'Die Krystalliten' pp. 123-73, Bonn, 1875. 'Spherulitic Crystallisation' Bull. Phys. Soc. Wash-1. H. VOGELSANG. 2. J. P. IDDINGS. ington, vol. xi (1891) pp. 445-64. 'The Natural History of Igneous Rocks' 1909, 3. A. HARKER. pp. 272-80. 'Zur Entstehung der Harnsteine und ähnlicher Kon-4. H. SCHADE. zentrich geschichteter Steine Organischen & Anorganischen Ursprungs' Kolloid Zeitschr. vol. iv (1909) pp. 175-80. 'Ueber Konkrementbildungen beim Vorgang der Trop-Id.5. figen Entmischung von Emulsion-Kolloiden' Kolloidenm. Beihefte i (1910) pp. 375-90
'Chemische Reaktionen in Gallerten' Düsseldorf, 6. R. E. LIESEGANG. 1898. See also 'Geologische Diffusionen' pp. 81-92, Dresden, 1913. 'On the LIESEGANG Phenomenon in Gels' Science 7. S. C. BRADFORD. Progress, vol. x (1916) pp. 369-73.

'Adsorptive Stratification in Gels' Biochem. Journal, vol. x (1916) pp. 169-75.

'Adsorptive Stratification in Gels-II' Ibid. vol. xi

(1917) pp. 14-20. On the Theory of Gels' *Ibid.* vol. xii (1918) pp. 351-81.

'On the Gelatin of the Natural Emulsoids' Science Progress, vol. xii (1917) pp. 63-70. 'Reversible Sol-Gel Transformation' (from 'The

Physics & Chemistry of Colloids') Faraday Society discussion, 1921.

'On the Theory of Gels-IV' Biochem. Journ. vol. xvii (1923) pp. 230-39. 'On Oolites & Spherulites' Journ. Geol. vol. xxvi

(1918) pp. 593-609.

'Oolith & Stromatolith im Norddeutschen Buntsand-stein' Zeitschr. Deutsch. Geol. Gesellsch. vol. lx (1908) pp. 68-125.

'Notes on Concretions' Proc. Geol. Assoc. vol. xxvii (1916) pp. 192-97.
'On the Passage of a Seam of Coal into a Seam of

Dolomite 'Q. J. G. S. vol. lvii (1901) pp. 297-306. 'The Glenboig Fireclay' Proc. Royal Soc. Edinb.

vol. xxx (1910) p. 359. 'The Petrology of the Sedimentary Rocks' 1913,

Summary of Progress of the Geological Survey for

1897 (1898) p. 127.

'The Geology of the North Staffordshire Coalfields' Mem. Geol. Surv. 1905, p. 226. 'The Geology of the Zambesi Basin' Q. J. G. S.

vol. lxiii (1907) p. 175. 'Monograph on the Constitution of Coal' Dept. Sci.

Industr. Research, 1918, pp. 16-17.
'Geology of the Weald' Mem. Geol. Surv. 1875, pp. 47-48.

'The Geology of the North-Western Part of the Wankie Coalfield' Bull. Geol. Surv. S. Rhodesia, No. 4 (1914) p. 44.:

'Vorkommen & Entstehung der Kaolinerden des Osttnüringischen Buntsandsteinbeckens' Zeitschr. Prakt. Geol. vol. xviii (1910) p. 365.

Id.

Id. Ω.

10. Id.

11. Id.

12. Id.

Id.13.

14. W. H. BUCHER.

15. E. KALKOWSKY.

16. G. ABBOTT.

17. Sir Aubrey Strahan.

18. J. W. GREGORY.

19. F. H. HATCH & R. H. RASTALL.

20. Sir JETHRO TEALL.

21. W. GIBSON.

22. G. W. LAMPLUGH.

23. M. C. STOPES & R. V. WHEELER.

24. W. TOPLEY.

25. B. LIGHTFOOT.

26. F. WEISS.

27. Sven Odén.

28. J. W. GRUNER.

29. E. C. HARDER.

30.

31. BORIS POPOFF.

'Die Huminsäuren: Chemische, Physikalische & Bodenkundliche Forschungen' Kolloidchem. Beihefte ii (1919) p. 104.

'Origin of Sedimentary Iron Formations' Economic Geology, vol. xvii (1922) pp. 407-60.

'Iron-depositing Bacteria & their Geologic Relations' U.S. Geol. Surv. Prof. Paper cxiii (1919) pp. 64-84. Summary of Progress of the Geological Survey for

1922 (1923) p. 125.

'Eine Neue Untersuchungsweise Sphärolithischer Bildungen' Min. Petr. Mitt. vol. xxiii (1904) pp. 153-79.

VI. APPENDIX.

Form of the Surface of Contact between Two Interfering Spherulites.

Boris Popoff (31) first pointed out that the form of the surface of contact between two interfering spherulites may throw light on the law of their growth. Assuming that the spherulites had grown outwards at a constant rate: that is, that the radius had increased proportionally to the time, he showed, from a consideration of the equations of a point on the surface of contact, that the form of this surface for spherulites of unequal size would be a hyperboloid of revolution concave towards the smaller spherulite. A section through the centres of the two spherulites would show a hyperbola of increasing eccentricity (that is, increasing curvature towards the smaller spherulite) as the centre of the smaller individual approached the periphery of the other. Popoff examined various artificial spherulites of sulphur and a number of igneous spherulites, and showed that the contactsurface agreed with this assumed law of $t \propto r$. Later, Dr. A. Harker (3) considered the laws of spherulite growth $t \propto r$ and $t \propto r^2$, and showed that the law of growth $t \propto r^2$ would give a plane-surface of contact with spherulites of unequal size. Spherulites in volcanic rocks from Antrim, Mull, and Skye were cited as having grown according to this law.

In the following consideration it will be assumed that the two spherulites have both grown according to the same law (since they are adjacent and in the same medium) and that they are of unequal size—since spherulites of equal size would give a plane

contact-surface, whatever the law of growth.

Let the spherulites be A & B (fig. I, p. 694), and let A (the larger spherulite) have attained a diameter =2c when B spherulite commences to grow. Let P be any point on the surface of contact, and T the foot of the perpendicular on to the line joining the two centres A, B.

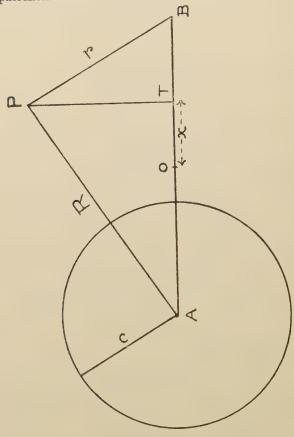
$AP^{2}-PB^{2}=AT^{2}-TB^{2}=AB(AT-TB)$. Then

If the mid-point between A and B is O, with OT=x, and if we let AB = 2a, then $AP^2 - PB^2 = 4ax$.

Now, AP & PB are simultaneous radii of the spherulites A & B for the point of contact P, and, if we denote these radii by R and r, we have

 $R^2 - r^2 = 4ax. \qquad . \qquad . \qquad . \qquad [1]$

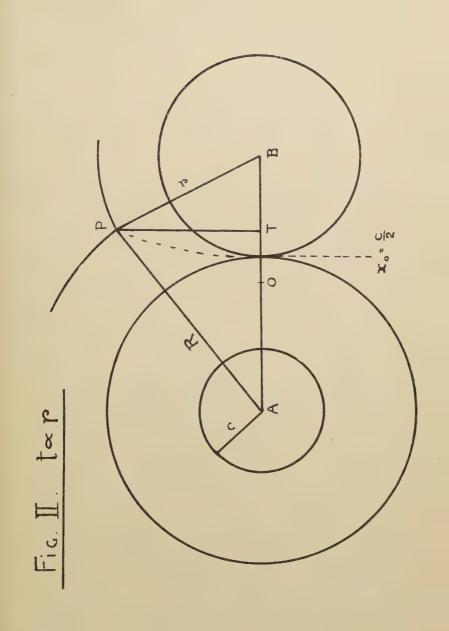
This is a geometrical relationship independent of the law of growth of the spherulites.

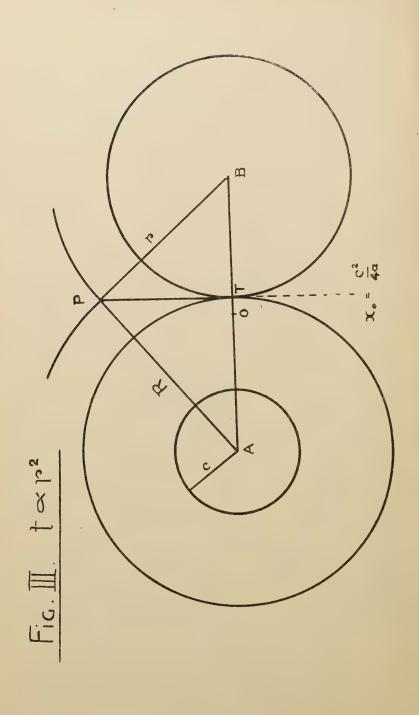


If we now assume that the spherulites have grown outwards according to the law $t \propto r$: that is, that the radius has increased proportionally to the time, then R-c=r, and this gives with equation [1]

or $(c+r)^2 - r^2 = 4ax$ or $4ax = c^2 + 2cr$.

In this equation the only variables are x = OT and r, the radius of the smaller spherulite. If r is increased, x must increase, and





P moves to the right. The surface of contact is concave to the smaller spherulite. (See fig. II, p. 695.)

The spherulites first meet at the point x_0 , which satisfies the

condition

$$a + x_0 - (a - x_0) = c$$
, or $x_0 = \frac{c}{2}$.

From the relation R-r=c, it follows by geometry that the locus of P is one branch of a hyperbola, with foci at A and B and eccentricity $AB \div c$.

If we make the law of growth such that $t \propto r^2$: that is, the square of the radius proportional to the time, then we have

$$R^2 = r^2 + c^2$$
,

and, eliminating R as before, with equation [1] we have $4ax=c^2$. That is, the point T is fixed for all the values of r, and as r is increased, P must move along the perpendicular to AB through T. (See fig. III, p. 696.) The contact-surface is a plane perpendicular to AB through T, and its distance from the point O is given by x_0 , where

 $(a+x_0)^2-(a-x_0)^2=c^2$. $x_0=\frac{c^2}{4a}$.

Taking now the general case where the nth power of the radius is proportional to the time, we have

$$R^{n}-c^{n}=r^{n}$$
 or $R^{2}=(c^{n}+r^{n})^{\frac{2}{n}}$,

which with equation [1] gives

$$4ax = (c^n + r^n)^{\frac{2}{n}} - r^2$$
. [2]

This equation expresses the relationship between the coordinate x, of a point on the surface of contact of two spherulites, and r, the corresponding radius of the smaller spherulite, for given values of c and any positive value of n.

The differential coefficient of this expression relative to r is

given by

$$4a\frac{dx}{dr} = 2r \left[r^{n-2} (c^n + r^n)^{\frac{2}{n}-1} - 1 \right]$$
$$= 2r \left[\left[\left(\frac{c^n + r^n}{r^n} \right)^{\frac{1}{n}} \right]^{2-n} - 1 \right].$$

If we make n=2 this expression vanishes, or the rate of increase of x relative to r is zero: that is, x is constant for all values of r (as we have seen). If n is positive but less than 2, the fraction

$$\left[\left(\frac{c^n+r^n}{r^n}\right)^{\frac{1}{n}}\right]^{2-n}$$
 is greater than unity for all positive values of r

and c, and the rate of increase is positive. Hence x increases as r is increased, and the surface of contact is concave to B, the smaller spherulite, for all values of n less than n=2.

For values of n greater than n=2 the fraction $\left[\left(\frac{c^n+r^n}{\sqrt{r^n}}\right)^{\frac{1}{n}}\right]^{2-n}$

is less than unity for positive values of r and c, and the rate of increase is negative: that is, x decreases as r is increased. Hence the surface of contact curves to the left, or becomes concave towards A, the larger spherulite. The value of x can never become negative, however, since (see equation [2]) the value of

 $(c^n+r^n)^{\frac{2}{n}}$ will always be greater than r^2 for any positive value of r. As r becomes very great, x approaches zero, and in the limit when $r=\infty$, x=0. The plane perpendicular to and bisecting AB (that is, through x=0) is an asymptotic plane for all contact-curves formed by values of n>2.

The point of first contact x_0 is given from the equation

$$(a+x_0)^n - (a-x_0)^n = c^n$$

which for positive integral values of n may be written

$$2x_0 = c \frac{c^{n-1}}{(a+x_0)^{n-1} + (a+x_0)^{n-2}(a-x_0) \cdot \dots \cdot (a-x_0)^{n-1}}$$

If c is less than a, the fraction on the right decreases as n is increased, and for very large values of n, x_0 approaches zero. The point of first contact (or apex of the surface of contact) shrinks towards the asymptotic plane as n is increased, and the surface of contact flattens towards this plane. For the value n=2 it has been shown that the surface of contact is a plane

through $x_0 = \frac{c^2}{4a}$, perpendicular to AB. This plane and the parallel asymptotic plane through x=0 contain all the contact-

parallel asymptotic plane through x=0 contain all the contact-surfaces given by various values of n>2. (See figs. IV & V, pp. 699 & 700.)

In the foregoing considerations we have examined the relation between x, the horizontal coordinate of P, and r, the corresponding radius of the smaller spherulite. To obtain y, the other rectangular coordinate of P, we have the equation

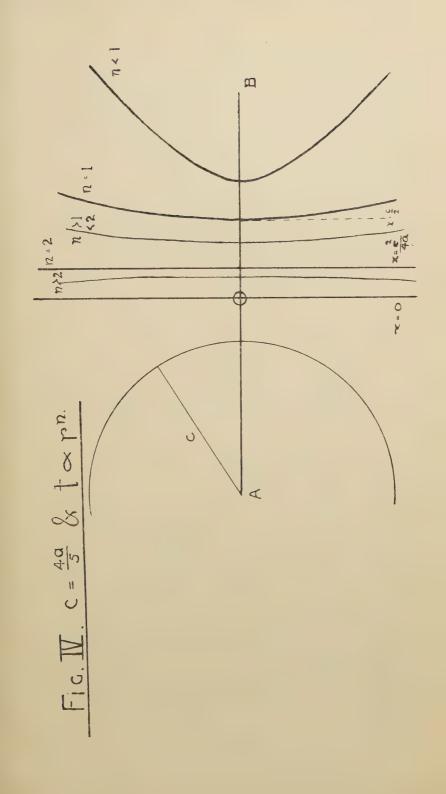
$$(x-a)^2 + y^2 = r^2$$
.

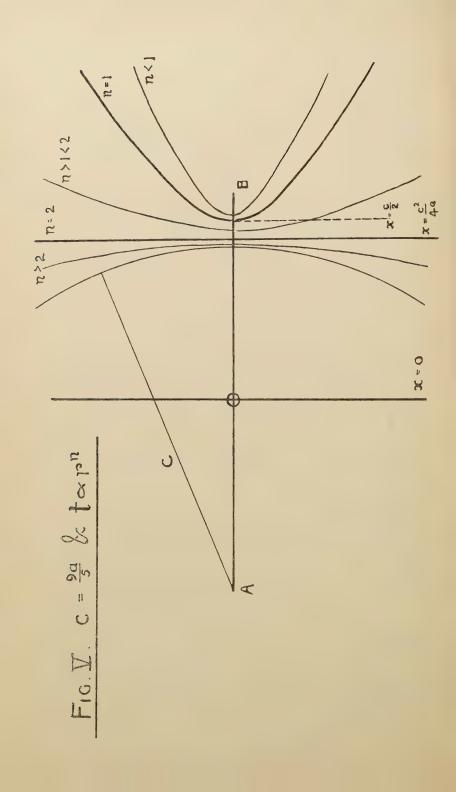
This is the equation to the circle through P with centre B. Combining this with equation [2], we obtain

$$(4ay)^{2} = \left[(c^{n} + r^{n})^{\frac{1}{n}} + 2a + r \right] \times \left[(c^{n} + r^{n})^{\frac{1}{n}} + 2a - r \right] \times \left[(c^{n} + r^{n})^{\frac{1}{n}} - 2a + r \right] \times \left[2a + r - (c^{n} + r^{n})^{\frac{1}{n}} \right].$$

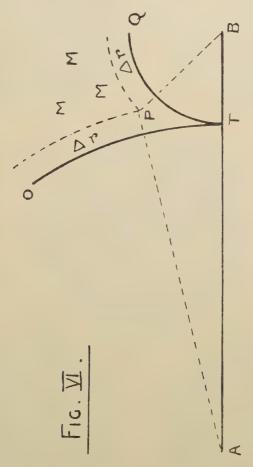
This expression contains only the variables y and r, and from an examination of the last two terms it can be shown that y has only real values between certain definite limits of r and x.

For values of c greater than c=a the apices of the contact-





surfaces become crowded towards B, and when c=2a: that is, when B centre falls on the periphery of A, all the apices of the contact-surfaces coincide with B. The shapes of the contact-surfaces for values of $c=\frac{4}{5}a$, and $c=\frac{9}{5}a$ are shown diagrammatically below for various values of n.



The foregoing results have been obtained by assuming growth laws of $t \propto r^n$, giving n any positive value without regard to limits which may be imposed by conditions of crystallization. Let us now consider the case of two spherulites growing by crystallization from a supersaturated medium.

Let OT and TQ be parts of the surfaces of two growing spherulites which have established contact at T, the outward growth

being towards the medium M. Let the centre of the larger spherulite be A, and that of the smaller B (see fig. VI, p. 701).

It is evident that with crystallization equally free to take place on both surfaces, the same increment in thickness will be added to each surface in a given time. This will be true, however the conditions may change in the medium during the growth of this layer, since both surfaces will be equally affected by such changes. If P represents the last point of contact after an addition of increment Δr to each spherulite

$$AP - AT = \Delta r = PB - TB$$
.
 $AP - PB = AT - TB = constant$.

It follows from this (p. 697) that the locus of P is one branch of a hyperbola, and we may write, using the same notation as before.

 $4ax = c^2 + 2cr,$

where c is the radius of A when B spherulite commences to grow; r is the radius of the smaller spherulite for the point P; and x is the horizontal coordinate of P from the origin O, the mid-point between A and B, and AB=2a.

The eccentricity of this hyperbola, which is given by $\frac{2a}{c}$, determines the concavity of the contact-surface towards B, and is independent of any changes in the rate of crystallization owing to changes in the medium. The concavity towards B is determined only by the relative nearness of B centre to the periphery of A spherulite when B centre commences to grow. If, however, the medium contains some foreign substance which becomes partly expelled outwards by the growing spherulites, so that crystallization is progressively impeded (say, in proportion to some power of the radius), then the thickness of the shell added to A surface in a given time will be less than that added to B, with the result that the surface of contact becomes less concave towards B. Increasing this progressive retardation of radial growth may be regarded as equivalent to increasing the value of n from unity upwards in the expression

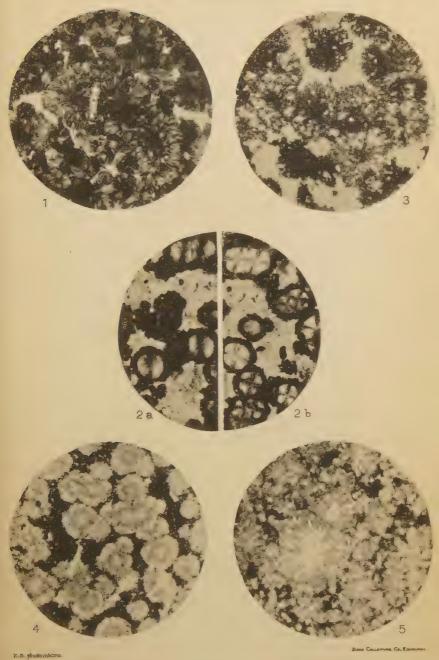
 $4ax = (c^n + r^n)^{\frac{2}{n}} - r^2.$

This increase, as we have seen, causes the contact-surface to become less concave towards B, and eventually to become convex towards B (or concave towards A).

Progressive impediment to outward growth would tend to limit the size of the spherulites, unless the impeding barrier became occluded as a 'zone', when further limited growth would be possible.

A notable feature of the sedimentary siderite-spherulites is this tendency towards a definite size, as compared with most igneous and artificial spherulites.

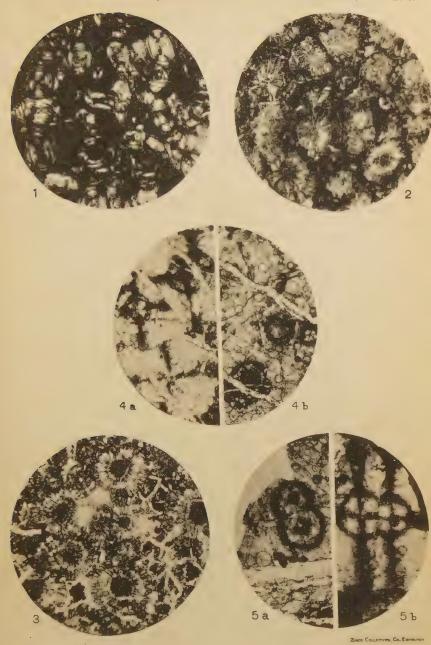
QUART. JOURN. GEOL. SOC. VOL. LXXXI, PL, XLII



FAIRLIGHT and WANKIE SPHERULITES.



QUART. JOURN. GEOL. SOC. VOL. LXXXI, PL. XLIII.



CLEVELAND OOLITE: SPHERULITES FROM INDIA and PORTUGAL.

E.S. photomicro.



EXPLANATION OF PLATES XLII & XLIII.

PLATE XLII,

Fig. 1. Section of a Fairlight nodule, showing the bladed variety of spherulites. Ordinary light. × 10. (See p. 672.)

Section of a Fairight nodule, showing the fibrous variety of spherulites: (a) with lower nicol showing 'relief brush'; (b) with crossed nicols (note the slightly curved contact-lines). × 8. (See p. 672.)
 Section of a Fairlight nodule having a sandy matrix. Note the

 Section of a Fairlight nodule having a sandy matrix. Note the sand-particles within the spherulites. Ordinary light. × 15. (See p. 672)

 Section of a Fairlight nodule, leached and dyed to show the distribution of clayey sediment within the spherulites. Ordinary light. × 9. (See p. 674.)

 Section of spherulitic hæmatite, Wankie Coalfield, leached and dyed to show the distribution of clayey matter within the spherulites. Ordinary light. × 18. (See p. 674.)

PLATE XLIII.

- Fig. 1. Leached section of Cleveland oolite, showing the distribution of siliceous matter in the ooliths. Crossed nicols. × 18. (See p. 674.)
 - Leached section of a Karanpura spherulite-nodule, showing the radial distribution of organic sediment within the spherulites, and the curvature of the radii towards certain directions. Ordinary light. × 5. (See pp. 678, 679.)

 Section of a Jherria coaly spherulite-nodule, showing the zoning and partial infilling of shrinkage-cracks in the coaly matter by secondary calcium phosphate. Ordinary light × 10. (See p. 680.)

4 Section of mixed carbonate-rock, Santo Domingo (Portugal), showing spherulites containing numerous radiolarian casts and a dark zone. Note the shrinkage-cracks filled in with quartz: (a) ordinary light; (b) crossed nicols. × 16. (See p. 683.)

 Another section of the same rock, showing two interfering spherulites with zones and included radiolarian casts: (a) ordinary light;
 (b) crossed nicols. × 16. (See p. 683.)

DISCUSSION.

Mr. A. F. HALLIMOND said that it was most interesting to have a comparison of the foreign sphærosiderites with the well-known English examples. Coal-Measure ironstones were, broadly speaking, of three types: fine-grained siderite-mudstones, peculiar carbonaterocks which sometimes occupied the position of coal-seams (like that from Wirral described by Sir Aubrey Strahan), and spherosiderites. The formation of the latter was attributed by the Author to adsorption, but it was difficult to imagine any conditions in which the 70 to 80 per cent. of ferrous carbonate in a rich spherosiderite could be adsorbed by 30 to 20 per cent. of siliceous clay. We could not at present go much farther than to say that, by some means, the clay was supplied from without with a solution that became more than saturated with respect to siderite, and that precipitation occurred round nuclei, usually very numerous, which under certain conditions were rarer and gave rise to sphærosiderites. The spherulitic form resulted from a special kind of nucleus, and

Q. J. G. S. No. 324.

the conditions for spherulitic growth from solutions had been investigated experimentally in a series of papers published of late years in the Bulletin of the French Mineralogical Society. English spherosiderites had been described by the speaker in a newly published volume of the 'Special Reports' of the Geological

Survey (vol. xxix) on the bedded iron-ores.

The leached and stained microsections afforded a very beautiful demonstration of the distribution of the included clayey matter in the spherules. For the detection of siderite itself, with the assistance of Mr. R. Sutcliffe, of the Geological Survey Laboratory, he had succeeded in obtaining a method of staining siderite without destroying the calcite. The polished face of the chip was immersed for a few minutes in boiling strong caustic potash solution, to which a little hydrogen peroxide was added at intervals. This gave a remarkably uniform brown stain all over the siderite surfaces, and the chip could be washed and the section completed in the usual way. Mr. Hallimond then exhibited microsections of spherosiderites and of rocks stained by the above method.

Mr. A. O. HAYES said that he had studied the occurrence of siderite in the Wabana iron-ore of Newfoundland thirteen years ago, and as these are hamatite-deposits of marine origin, it may be of interest to compare and contrast briefly the freshwater and the

marine types.

The Wabana iron-ore deposits, belonging to the British Empire Steel Corporation, form the largest known single reserve in the British Empire. They are of Ordovician age, and their similarity to certain oolitic hæmatite-deposits in Wales of Arenig age, as well as a marked resemblance of some portions to the ('leveland ores, has been described by Mr. Hallimond in his recently published report on the Iron-Ores of Great Britain.

While the general character of the Wabana iron-ore is hæmatitic, in the upper part of a bed 7 feet thick the oolitic hæmatite is capped by oolitic siderite and chamosite several inches thick. Siderite occurs interstitially in smaller quantity throughout the

upper half of the bed.

The siderite is associated with contic chamosite, a hydrated errous silicate of iron and magnesia, and the latter has been partly destroyed, with (in some places) pseudomorphs of siderite retaining the colitic form of the chamosite. No original colitic siderite was observed, and the speaker concluded that the chamosite, which forms an integral part of all the ore, was deposited, to some extent at least, before the hæmatite and siderite were precipitated in the sea-bottom deposits.

The large quantity of decaying organisms, including annelids, trilobites, and bivalves, mainly Lingulæ, which undoubtedly were partly buried in the soft iron silicate and hæmatite ooze, would supply carbon dioxide: this may have given rise to the formation of the ferrous carbonate, and would explain its destructive action

in replacing the silicated iron.

Thus, under the special conditions obtaining in these marine

deposits, no tendency for the siderite to adopt a spherical form was observed, in contrast with the examples cited from the coals and freshwater deposits.

Mr. A. Broughton Edge also spoke.

POSTSCRIPT TO THE DISCUSSION.

The AUTHOR agrees with Mr. Hallimond that it is difficult to imagine how 30 to 20 per cent. of siliceous clay sediment could adsorb 70 to 80 per cent. of ferrous carbonate. Concentration by adsorption could not have been brought about if only the clayey matter within the spherulite-nodules had been effective as an adsorbent. All the spherulite-siderites examined by the Author in the field (and most of the clay-ironstone nodules), constitute only a small proportion of the argillaceous beds in which they lie. In the Fairlight Clays the proportion of clayey sediment to ferrous carbonate over the full thickness of the bed is at least 10:1, and probably much higher. The spherulites in the Indian coalseams occur as nodules or scattered shot, within some of the best seams, and obviously constitute only a very small proportion of the total volume of the seam. The Author's view is that, in all probability, the whole of the finely-divided clayer or coaly sediment within the bed has been equally effective as an adsorbent, and that the local concentration now represented by carbonate-nodules or concretions has been brought about by the saturated solutions migrating or diffusing towards crystallization-centres, as described above.

The Author does not agree with Mr. Hallimond that the spherulitic form has resulted from a special kind of nucleus. The spherulites described above, from widely-separated localities, have a number of features in common, such as (1) freshwater origin, (2) absence of shelly carbonate of lime, (3) absence of chamosite or other silicates of iron, etc.; but there is no similarity in the physical condition or degree of fineness of the sediments, which vary from fine silts through clays to organic matter. Sometimes the spherulites show a nucleus of organic matter, pyrites, or a sandgrain, but the majority of them show no visible nucleus.

The radiating spherulitic form of the carbonate appears to be due to crystallization from supersaturated solutions held within partly-colloidal sediment. The distended sediment appears to have affected the process of crystallization only in a minor degree, by providing channels along which the solutions could diffuse; it became, however, so dense eventually (either by expulsion from the growing spherulite or by the settling of the sediment, or both) that diffusion was impossible, and the spherulite ceased to grow.—

E. S., October 7th, 1925.

GENERAL INDEX

TO

QUARTERLY JOURNAL THE

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

ABBOTT, G., obituary of, lxxviilxxviii.

Acanthopleuroceras lepidum sp. nov., 651-52 & pl. xl.

Acidaspis-erinaceus Torver Zone, Beck, petrography of, 132.

Ailstone (Worcestershire), Pleistoc. non-marine mollusca from, 164.

Albertella bosworthi, 319 & pl. xv. 'Alkali-gabbros' in Sierra Leone, 208. Allanite in Hökulvikurgil rocks, 331. Almandine, zone of, in S. Highlands,

104. Alpine Range, formation of, vii-viii. Alveolina lepidula, 439-40 & pl. xxiv.

---- oblonga, 440-41 & pl. xxiv. - ovicula sp. nov., 439.

---- subpyrenaica, 434-35 & pls. xxiii-xxiv.

Alveolina Limestone, use of term,

Amphibolites (& hornblende-schists) of Sierra Leone, 197.

Analyses of dacite, &c., 484; of spilites, 513; of spherulites, &c. fr. Fairlight Clays, 675; of Coal-Measure spherulites, &c., 676, 677, 680, 681, 682; of spherulites w. radiolaria in rhombohedral carbonate, 684.

Ancon (Ecuador), clay pebble-bed of, 454-62 figs. & pls. xxviii-xxix.

Andrew, G., on the Llandovery Rocks of Garth (Breconshire), 389-405. w. vert. sects. & pl. xxii (map); (& O. T. Jones), on the Relations between the Llandovery Rocks of Llandovery & those of Garth, 407-14 w. map.

ANDREWS, C. W., 61; obituary of,

Annual General Meeting, ix et seqq. Aran Valley (Merioneth), Bifidus Slates of, 551-52.

Arenig Series in Cader Idris district, 546-47.

Argenteus Zone, 'green streak' in, 131, 132,

Armatum Bed, 601 et seqq., 632.

Arnioceras cf. bodleyi, 638.

- crassicosta sp. nov., 637-38 fig. & pl. xxxix.

- cf. falcaries, 638. ____ cf. flavum, 640.

- fortunatum, 638.

---- cf. geometricum, 640. ____ hartmanni, 636-37.

- hodderi sp. nov., 639 fig. & pl. xxxviii.

cf. nigrum, 640.
notatum sp. nov., 638-39 fig. & pl. xxxix.

- cf. speciosum, 638. --- cf. spirale, 640.

Ashby-de-la-Zouch (Leicester), 'dreikanter' from, exhibited, exxiv.

Ashgillian succession in Lake District, 114.

ASHMAN, W. J., 616. Assets, statement of, xli.

Assilina granulosa, 441-43 & pl. xxvi.

- leymeriei, 444 & pl. xxv.

Atherfield (I. of Wight), Iguanodon atherfieldensis from, 1-61 figs. & pls. i-ii.

Atrypa-flexuosa Zone, 121, 131. Auditors elected, vi.

Augite- (& hornblende-) andesites of Rhobell Fawr, 479-80.

Autogeneric Stage (in development of Trilobites), 251.

Autospecific Stage (in development of Trilobites), 251-52.

Avon R. (Warwickshire), river-terraces of lower valley, 137-69 figs. & pl. x (map & sect.).

Bailey, E. B., 110; on the Tertiary Igneous Geology of the Island of Mull, exxv-exxvi.

Bala Series, in Llandovery district, 351-52; in Garth district, 390-92; 'Bala Mudstones' in Rhobell Fawr district, 518-19; Bala M. in Cader Idris range, 567-69.

Balance-sheet for 1924, xxxvi-xxxvii, Baldry, R. A., 461-62; (& C. B. Brown), on the Clay Pebble-Bed of Ancon (Ecuador), 454-60 figs. & pls. xxviii-xxix.

Baluchistan, see Laki Series.

BARLOW-JAMESON Fund, list of applications of, xxxiii.

BARROW, G., 110-11.

BARROW, L., 153.

Basaltic rocks of Rhobell Fawr district, 513-15 w. chem. anals.; relat. of do. to spilites, 515-16.

Basement Group (Lr. Llandovery) in Llandovery district, 353-55; in Garth district, 392-94; B. G. (Ordovician) in Rhobell Fawr district, 494-96; B. G. (Arenig) in Cader Idris district, 546-47.

Batch Quarry (Somerset), 615.

BATHER, F. A., obituary of Th. Thoroddsen, lii.

Bengeworth (Worcestershire), Pleistocene Unio from, 164-65.

Benson, W. N., obituary of E. R. Stanley, lxxviii-lxxix.

Benthonic organisms in Skelgill Beds, &c., 120-22 fig., 127-28.

BERDINNER, H. C., 533.

Bibliography of fossil elephants, 84–85; of metamorphism in S. Highlands, 109; of Pleistocene deposits, &c., 163: of the geology of Sierra Leone, 218; of Trilobites, 316–18; of Foraminifera, &c., 449–51; of the Radstock Lias, 660–61; of spherulitic siderite, &c., 692–93.

Bifidus, see Didymograptus.

Bigsby Medallists, list of, xxxii; B. Medal awarded to C. W. Knight, xlv-xlvi.

Bince's Lodge Quarry (Somerset), 609, 612 fig.

Biotite, zone of, in S. Highlands, 103. Bird-Rock Anticline (Cader Idris), 577.

Bird's Quarry (Somerset), 610.

Birlingham (Worcestershire), Pleistoc. non-marine mollusca from, 143, 165.

'Black Sea' conditions during deposition of graptolitic muds, 125– 27 fig.

Bloomfield Quarry (Somerset), 619. Bolan Pass (Baluchistan), Laki Series in, 420-21.

BOSWELL, P. G. H., 135, 193-94, 691. Bowldish (or Bold Ditch) Quarry (Somerset), 608-609.

Brammall, A., proceeds of Wollaston Fund awarded to, xlvi.

Brathay Flags, 114.

Breithdalsvik, see Iceland.

Bricklehampton Bank, Pleistoc. nonmarine mollusca from, 165; see also Cropthorne.

BRIGHTON, A. G., 418.

Broom (Worcestershire), Pleistoc. non-marine mollusca from, 165.

Browgill Beds, see Stockdale Shales. Brown, C. B. (& R. A. Baldry), on the Clay Pebble-Bed of Ancon (Ecuador), 454-60 figs. & pls. xxviii-xxix.

Bryn Britl. Beds, 548-49. Bryn-y-saeson Beds, 173, 180. Bucklandi Bed, 601 et seqq., 630. Buckman, S. S., 597, 662-63.

Bull, A. J., 533.

Burls, H. T., obituary of, lxxiv-lxxv.

Bwlch-pen-Barras Beds, 174-75; Bwlch-pen-Barras Fault, geol. of country betw. Moel Fammau Fault and, 187-88; do. betw. Plymog Fault and, 188.

Cader Idris range (Merioneth), geology of, 539-94 figs. & pls. xxxiiixxxvii.

Calcareous Nodule Group (Middle Llandovery), 361-63; do. (Upper Llandovery), 367-70.

Cambrian in Rhobell Fawr district, 465-69; (Upper), in Cader Idris district, 545-46.

Camerton Quarry (Somerset), 617. Cancrinite-syenite in Sierra Leone,

Cauldron-subsidences, lxxxv. Cefn-Goleu Beds, 173, 179-80. Cefn-hir Ashes, 553-54.

Cerniau (Merioneth), dacite of, 483-84 w. chem. anal., 486 fig.

Chadbury (Worcestershire), Pleistoc. non-marine mollusca from, 165.

Chapel Quarry (Somerset), 611.

Charnockitic rocks of Sierrra Leone, 198-99.

Chellean implements fr. Hyde Park, exxvi-exxvii.

Chlorite, zone of, in S. Highlands,

Cilgwyn (Carmarthenshire), descr. sect. near, 353.

Clandown Colliery Quarry (Somerset), 600 fig.-604.

Clay-ironstone, relat of spherulitic siderite to, 690.

Clay pebble-bed of Ancon, 454-62 figs. & pls. xxviii-xxix.

Cleavage, &c. in Silurian of Clwydian range, 189-91.

Cleveland oolite, 674 & pl xliii. Clutton, see Hunter's Rest.

Clwydian range (N. Wales), Silurian of central part of, 170-94 & pl. xi (map).

Coal Measures, spherulitic ironstone from, 675-77 w. anals., 678-82 w. anals. & pl. xliii.

COBBOLD, E. S., 316.

COLE, G. A. J., obituary of, lxvi-

COLLET, L. W., on the Latest Ideas on the Formation of the Alpine Range, vii-viii.

Conocoryphidæ, &c., ontogenies of, 257-66.

'Continental shields', cviii.

Conygre Quarry (Somerset), 617.

COSSMANN, A. E. M., obituary of, xlix-li.

Council, annual report of, ix-xi; (& Officers) elected, xxv.

Cox, A. Hubert, 135-36, 218, 533, 535-36; on the Dissection of Pitching Folds [title only], exxiii; on the Geology of the Cader Idris Range (Merioneth), 539-92 figs. & pls. xxxiii-xxxvii, 593-94.

Cox, L. R., on the Fauna of the Basal Shell-Bed of the Portland Stone of the Isle of Portland, exxvii.

Craig-y-Llam (or Upper Acid) Group, 564-67.

Crogenen Slates, 549-51.

CROOK, T., obituary of G. A. J. Cole, lxvi-lxix.

Cropthorne (Worcestershire), sect.

through No. 4 Terrace at, 146; sect. through Bricklehampton Bank, 147; Pleistoc. non-marine mollusca from, 166.

CROSFIELD, (Miss) M. C. (& Mrs. E. G. Woods), on the Silurian Rocks of the Central Part of the Clwydian Range, 170-92 & pl. xi (map).

Cross-faults, xciii.

'Crystal tuffs' of Rhobell Fawr, 478 - 79.

Ctenopleural Stage (in development of Trilobites), 250-51.

Cullis, C. G., 677, 691.

CUNNINGHAM-CRAIG, E. H., 111-12. CUNNINGTON, R. H., exxvii.

Dacite of Cerniau, 483-84 w. chem. anal., 486 fig.

Dalmanitina hausmanni, 319 & pl.

- socialis, ontogeny of (& its comparison w. Paradoxides), 280-85.

DANIEL-PIDGEON Fund, list of recipients, xxxiii.

DAVIES, A. M., 453, 664.

DAVIS, W. M., elected For. Member, exxix.

Defford (Worcestershire), Pleistoc. non-marine mollusca from 166-67.

'Degrees' (in development of Trilobites), 225 et segq.

Denbighshire Series on the Clwydian range, table facing p. 180.

DENNING, G., 597.

DEWEY, H., elected Auditor, vi; on Chellean Implements fr. Hyde Park, exxvi-exxvii.

Dictyopyge, affinities w. Woodthorpea, 96 - 97.

Didymograptus-bifidus Beds in Cader Idris range, 548-53.

Diorite-porphyry of Foel Cae Poeth, 485-86 fig.

Discocyclina archiaci var. baluchistanensis nov., 446-47 fig. & pl.

DIXEY, F., on the Geology of Sierra Leone, 195-229 & pls. xii-xiv.

Dolerites of Sierra Leone, 216-17; of Hökulvikurgil, 326 et seqq., 332 et seqq.; in Rhobell Fawr district, 519 et seqq., 523 fig., 525 figs.; in Cader Idris range, 569-70.

Dolgelley Beds in Rhobell Fawr dis-

trict, 466-68.

Donors to Library, lists of, xiv-xix; to Voluntary Publication Fund, list of, xx.

Douglas, J. A., 460-61; re-elected Secretary, xxv.

Douvillé, H., 418.

'Dreikanter' fr. coal-seam exhibited, exxiv.

Dunghan Limestone, 420-21.

Dunkerton Colliery (Somerset), Lias near, 617, 622-25 figs.

Dwarf fossils, 121 fig.

Dyke, composite, fr. E. Iceland, 325–43 figs. & pls. xix-xx.

Dysynni Fault (Cader Idris), 583.

Earth's rotation, retardation of, exvii et segg.

Echinodermata of Laki Series, 432–33.

Echinoidea fr. the Portland Stone & the Purbeck Beds, exxviii-exxix.

Eckington (Worcestershire), Pleistoc. non-marine mollusca from, 167. Edge, A. B., 691.

Eithinen (or Brachiopod-) Beds, 173,

Election of Auditors, vi; of Council & Officers, xxv; of Fellows, iii-iv, vi, viii, exxiii, exxiv, exxv, exxvi, exxix; of For. Members & For.

Correspondents, cxxix. Elephants, fossil, of Upper Thames Basin, 62-86 fig. & pls. iii-vi.

Elephas antiquus & E. trogontherii, 69-79 & pls. iii-vi

— primigenius, 80-83 & pl. vi. Elles, (Miss) G. L., 122, 131, 133, 170, 405.

Elliptocephala asaphoides, development of, 291-94.

Eocene (Lr.), see Laki Series. Estimates for 1925, xxxiv-xxxv.

Evans, J. W., 99, 136, 169, 194. 221, 341-42, 415, 593, 665: re-elected President, xxv; addresses to Medallists and recipients of Awards, xlii et seqq.; obituaries of deceased Fellows, &c., xlix-lxxix; on Regions of Tension, lxxx-cxxii.

Evesham (Worcestershire). Pleistoc. non-marine mollusca from, 167.

Fairlight Clays, spherulites in, 670-75 & pls. xlii-xliii w. anals.

FALCONER, J. D., 222; on the Geology of Nigeria, iv-v.

Fammau, Moel, see Moel Fammau. Farmborough Quarries (Somerset),

600 fig., 620. Faulting & folding in Cader Idris range, 574-83. FEARNSIDES, W. G., 533-34, 592-93. Fellows elected, iii-iv, vi, viii, exxiii, exxiv, exxv, exxvi, exxix; names read out, i, exxix; number of, xxi-xxiii.

Fenton Park (Staffs), spherulitic ironstone from, 675-76 w. anals.

Ffestiniog Beds in Rhobell Fawr district, 465-66.

Financial report, xxxiv-xli.

FLETT, Sir JOHN S., receives Lyell Award for J. A. Thomson, xlvii; obituary of J. J. H. Teall, lxiii-lxv.

Flosculina globosa, 435–39 & pls. xxiii xxiv.

Fluvioglacial deposits of Lr. Avon valley, 139.

Foel Cae Poeth (Merioneth), dioriteporphyry of, 485-86 fig.

Foliation of Sierra Leone granites, 202-203.

Foraminifera of the Laki Series, 434–53 fig. & pls. xxiii-xxvi; strati-graphical distribution of do., 432.

Foreign Members, list of, xxvi; F. M. elected, cxxix; Foreign Correspondents, list of, xxvii; F. C. elected, cxxix.

Fossil localities in Llandovery district, 383-88; see also Graptolite.

Gabbros, &c. of Sierra Leone, 207-208.

Gahnia (Sierra Leone), sandy plains of, 220 & pl. xiii.

Garth (Breconshire), Llandovery rocks of, 389-405 w. vert. sects. & pl. xxii (map); relats. betw. the foregoing rocks & those of Llandovery, 407-14 w. map.

GEIKIE, Sir Archibald, decease announced, iii; obituary of, lii lx.

Ghazij Shales, 420.

Gleviceras aff. ylevense, 642 fig. —— sp., 642.

GORDON, W. T., 533, 536.

Granites (& granite-gneisses) of Sierra Leone, 201–208 & pl. xii.

Granophyres in Cader Idris range, 571.74 & pls. xxxiii-xxxv.

Granophyric granites, &c. of Sierra Leone, 206-207.

GRANTHAM, R. F., obituary of, lxxi-

Graptolite localities in the Clwydian range, 181-82.

Graptolitic muds, conditions of deposition of, 116 et seqq., 122 et seqq. w. map & diagram.

Green, J. F. N., Lyell Medal awarded to, xliv-xlv.

GREENLY, E., 535.

GROOM, T. T., 224, 414.

Gryphæa aff. & cf. cymbium, 653.
—— aff. dumortieri, 652, 653 fig.

—— incurva var. crassirugata nov., 652-53 fig.

- aff. obliqua, 653 fig.

Guibaliceras guibalianum, 641.

GUPPY, (Miss) E. M. (& L. Hawkes). on a Composite Dyke from Eastern Iceland, 325-40 figs., 341 & pls. xix-xx.

Gurundih Colliery, see Ranegange.

HALLIMOND, A. F., 703-704.

Ham Quarry (Somerset), 612 fig., 614-15.

HARWOOD, H. F., 533.

Hawkes, L. (& Miss E. M. Guppy), on a Composite Dyke from Eastern Iceland, 325-40 figs., 341 & pls. xix-xx, 343.

HAWKINS, H. L., 663; on Echinoidea from the Portland Stone & the Purbeck Beds, exxviii-exxix.

HAYES, A. O., 704-705.

HEARD, A., on the Petrology of the District between Nevin & Clynnog-fawr (Carnarvonshire) [title only], viii.

Hemicidaris purbeckensis, exxviii. Heptacicephalic Stage (in develop-

ment of Trilobites), 248-49. Hercynian & post-Hercynian folding, lxxxix et seqq.

HERDSMAN, W. H., 335.

HERRIES, R. S., re-elected Treasurer,

Hettangian deposition in Radstock district, 626-27.

HICKLING, G., obituary of D. Woolacott, lxxvi-lxxvii.

Highlands, see Southern.

HILTON, H., on the Cooling of a Dyke, 340-41.

Hobbs Wall Quarry (Somerset), 620. Hodder, J., 597.

Hökulvikurgil (Iceland), composite dyke at, 325-43 & pls. xix-xx.

Holaspid Period (in development of Trilobites), defined, 226.

Holm, G., elected For. Member, exxix. Holmia kjerulfi, development of, 295– 96.

HOOLEY, R. W., on the Skeleton of Iguanodon otherfieldensis sp. nov., from the Wealden Shales of Atherfield (Isle of Wight), 1-60 figs. & pls. i-ii.

Hornblende-schists (& amphibolites) of Sierra Leone, 197; hornblende-syenites, ibid., 207; h.-lampro-phyre & h.-porphyry ibid., 208; hornblende- (& augite-) andesites of Rhobell Fawr, 479-80; hornblende-porphyrite defined, 485.

Huish Colliery Quarry (Somerset), 610-11.

010-11.

HUMPHREYS, J., 163.

Hunter's Rest Quarry (Somerset), 612 fig., 620-21.

Hyde Park (London), Chellean implements from, exxvi-exxvii.

Hydrocephalus, development of, 269-71 et seqq.

Iceland (E.), composite dyke from, 325-43 figs. & pls. xix-xx.

Iguanodon atherfieldensis sp. nov., 1-61 figs. & pls. i-ii.

ILLING, V. C., 323, 460.

Inclusions within Sierra Leone granites, 205-206.

Interfering spherulites, form of surface of contact betw. two, 693-702.

Iron-ore, colitic, in Cader Idris range, 556-59; see also Siderite.

Ironshot Limestone, 602 fig. Isostasy, principle of, ciii, cv.

JACKSON, J. W., 63.

Jamesoni Limestone, 601, 602 fig. et seqq., 632.

Jamieson, A. W., obituary of, lxxvi. Jherria Coalfield (India), spherulitic ironstone from, 680–81 w. anals. & pl. xliii.

Jointing, causes of, lxxxii.

JONES, O. T., 133-34, 405, 415-16, 534-35; on the Geology of the Llandovery District: Part I—the Southern Area, 344-88 figs. & pl. xxi (map); (& G. Andrew), on the Relations between the Llandovery Rocks of Llandovery & those of Garth, 407-14 w. map.

JONES, R. C. B., 383.

JONES, W. R., 343.

JORDAN, H. K., obituary of, lxxi. JUNNER, N. R., 221-22.

Karanpura Coalfield (India), spherulitic siderite from, 678–80 w. anals. & pl. xliii.

Kennard, A. S., 169; (& B. B. Woodward), on the Pleistocene Non-Marine Mollusca of the Avon Valley, 164–68.

Keuper of Nottingham, Woodthorpea wilsoni from, 87-99 figs. & pls. viiviii. KIDSTON, R., obituary of, lxix-lxxi. Kilmersdon Road Quarries (Somerset),

600 fig., 610. King, W. B. R., 119, 131, 170, 194. Kirthar Limestone (Lr.), 419, 420. KITSON, A. E., 218.

Kjerulfia lata, 319 & pl. xv.

KNIGHT, C. W., Bigsby

Medal awarded to, xly-xlvi.

Kundukonko (Sierra Leone), Plateau Sands of, 220 & pl. xiii.

Lag-faults, lxxxv.

Lake District, conditions of deposition of Stockdale Shales in, 113-36 figs.

Laki Series (Lr. Eocene) of parts of Sind & Baluchistan, 417-33 figs.

LAMPLUGH, G. W., 460, 665; Wollaston Medal awarded to, xlii-

LANG, W. D., 418, 663.

Laterite, basal, of Laki Series, 419, 427 - 28.

Lavas, basic, of Rokell River Series, 211-12; of Rhobell Fawr, 479-80, 508-13 figs. & pl. xxx; see also Dolerites, &c.

LEMOINE, P., elected For. Corre-

spondent, cxxix.

Leptoplastus salteri & other Trilobites, development of, 223-324 fig. & pls. xv-xviii.

Liassic rocks of the Radstock distriet, 595-666 figs. & pls. xxxviii-

Library, annual report of Committee, xii-xiii; lists of donors to, xiv-xix. Little Lawford (Worcestershire),

Pleistoc. non-marine mollusca from, 167.

Llandovery (Carmarthen), Llandovery rocks, &c. of, 344-88 figs. & pl. xxi (map); relats. of the foregoing w. those of Garth, 407-14 w. map.

Llandovery rocks of Garth, 389-405 w. vert. sects. & pl. xxii (map).

Llanfachreth, see Rhobell Fawr. Llanvirn-Llandeilo succession

Rhobell Fawr district, 503-506. Llanvirn (Lr.) Series in Cader Idris

district, 548-54. Llyn-Aran Anticline (Cader Idris),

577.

Llyn-Cau Mudstones, 564.

Llyn Gwernan (Merioneth), Bryn-Brith Beds near, 548-49.

Llyn-y-Gader Mudstones & Ashes, 559-61.

Llyn-y-Gafr Spilitic Group, 554-56. Long Handborough (Oxon.), elephantremains from, 69 et segg.

Loyabad Colliery, see Jherria.

Ludlow's Quarry, see Bird's Quarry. LYELL Medallists, list of, xxx; recipients of L. Award, list of, xxxi; L. Medal awarded to J. F. N. Green, xliv-xlv; proceeds of L. Fund awarded to J. A. Thomson & W. A. Richardson, xlvii-xlviii.

McDonald (Miss), A. I., 655.

MADSEN, V., elected For. Correspondent, exxix.

MANTLE, H. G., exhibits 'dreikanter'

fr. coal-seam, exxiv.

Map of metamorphic zones in the S. Highlands, pl. ix; map showing localities in Europe & Brit. Is. where the Stockdale Shales or their equivalents were deposited, 123; map illustrating the Pleistocene deposits of the lower valley of the Warwickshire Avon, pl. x; geol. sketch-map of the central part of the Clwydian range, pl. xi; geol. map of Sierra Leone, pl. xiv; geol. map of the area S.E. of Llandovery, pl. xxi; map of the Llandovery rocks of Garth, pl. xxii; map illustrating the relations between the Llandovery rocks of Llandovery & those of Garth, 408; sketch-map of parts of Sind & Baluchistan, 418; geol. map of the neighbourhood of Meting (Sind), 422; map showg. districts recently re-surveyed in N. Wales, 464; geol. map of district S.W. of Dolgelley, 488; geol. maps of Rhobell Fawr summit, 497, 498; geol. map of Moel Cors-y-Garnedd, 500; geol. map of Rhobell Fawr district, pl. xxxii; geol. map of Cader Idris district, pl. xxxvii; sketch-map of Somerset & Bristol Channel, 596; sketch-map of Radstock district, 599; geol. map of country nr. Dunkerton Colliery, 623; geol. map illustrating denuded pre-sauzeanum folds in Radstock district, 629.

MARR, J. E., 169, 170; elected Foreign Secretary, xxv; on the Conditions of Deposition of the Stockdale Shales of the Lake District, 113-31 figs., 136.

MAUFE, H. B., 678, 691.

Meraspid Period (in development of Trilobites) defined, 226.

Mesonacidæ, ontogenies of, 286-301; facial suture of, 301-305; summary of ontogeny & structure of (together w. their phylogeny), 306-309.

Mesoparial Stage (in Trilobites) defined, 307–308.

Metamorphic zones in S. Highlands of Scotland, 100-12 & pl. ix (map).

Metamorphism in Rokell River Series, 212-13.

Metaparial Stage (in Trilobites) defined, 307-308.

Meting Limestone & M. Shales, 419, 421 et seqq., 424-27.

Microdiorite-sill, 482 fig.; microdiorite defined, 486-87.

Microgranite, porphyritic, in Sierra Leone, 208.

Middle Pit (Somerset), 609-10.

MILLER, W. G., obituary of, lxxii-lxxiii.

Moel Arthur (N. Wales), geol. of country betw. Penline Fault and, 185-86.

Moel Cors-y-Garnedd (Merioneth), geol. sketch-map & sect., 500, 501. Moel Fammau (N. Wales), 172 et

seqq.
Moel Offrwm (Merioneth), Ordovi-

vician, &c., of, 503. MONCETON, H. W., elected Auditor,

Monograptus chimæra & M. ch. var. salweyi, 183.

---- colonus var. compactus, 183.

—— crinitus, 183.

—— leintwardinensis, zone of, in Clwydian range, 173, 180; M. l. & M. l. var. incipiens, 183.

—— nilssoni, zone of, ibid., 173-74, 174-76; M. nilssoni, 183.

--- uncinatus var. orbatus, 183.

—— sp. (? priodon) in Sierra Leone, 209, 214.

Mudstone & M. & Sandstone Groups (Lr. Llandovery), 355-60, 394-97; Shaly & Hard Mudstone Groups (Middle Llandovery), 364-66, 397; Lr. & Upper Greenish Mudstones (Upper Llandovery), 370-71, 397-99; Pale Mudstone Group (U. Llandovery), 372-73, 399. Mull (Hebrides), Tertiary igneous geology of, cxxv-cxxvi.

Mungar Quarry (Somerset), 616.

Murchison Medallists & recipients of M. Award, lists of, xxix; M. Medal awarded to Herbert H. Thomas, xliii-xliv; proceeds of M. Fund awarded to A. E. Trueman, xlvii.

Mynydd t'Isaf (Merioneth), microdiorite sill at, 482 fig.

Mynydd-y-Gader Rhyolitic Group, 547; M.-y-G. Faults, 581-82.

Nakari Nala, see Karanpura.

Names of Fellows read out, i, exxix. Nant-Caw Syncline (Cader Idris), 577.

Nepheline-sodalite-syenite in Sierra Leone, 207.

New Mold Road (N. Wales), geol. of country betw. Plymog Fault and, 188-89.

NEWTON, R. B., obituary of A. E. M. Cossmann, xlix-li.

Newtown Quarry (Somerset), 615.

NICHOLAS, T. C., 536.

Nigeria, geology of, iv-v.

NIGGLI, P., elected For. Correspondent, exxix.

Nodular limestones, origin of, 634-35.

Non-marine Pleistocene mollusca of Avon Valley, 164-68.

Norite, olivine-bearing, in Sierra Leone, 208.

Norton Hall Quarry (Somerset), 612– 13 fig.

Nottingham, see Woodthorpea. Number of Fellows, &c., xxi-xxiii. Nummulites atacicus, 444-45 & pl. xxv.

—— irregularis, 446 & pl. xxvi. —— mamilla, 445-46 & pl. xxvii.

—— subatacicus, 445 & pl. xxv.

Nuttall, W. L. F., the Stratigraphy of the Laki Series (Lower Eocene) of parts of Sind & Baluchistan (India), with a Description of the Larger Foraminifera contained in those Beds, 417-53 figs. & pls. xxiii-xxvi.

Obtusum Nodules, 601 et seqq., 630-31.

Offenham (Worcestershire), Pleistoc. non-marine mollusca from, 167.

Officers (& Council) elected, xxv. Olenellus, stages in ontogeny phylogeny of, 307–308.

Olenellus gilberti, development of, 290-91.

Olenidæ, &c., ontogenies of, 257-66. Oolitic iron-ore in Cader Idris range, 556-59; oolitic ironstone compared w. spherulitic siderite, 691.

Opertorbitolites douvilléi gen. et sp. nov., 447-48 & pl. xxvii.

'Opisthoparia' (& 'Proparia'), 285–86.

Orbitolites complanata, 447.

Ordovician of Rhobell Fawr district, 494-503; of Cader Idris district, 546-69.

Ostrea Beds, 601 et seqq.

Oxynoticeras williamsi sp. nov., 644 & pl. xli.

PACAUD, L., receives Bigsby Medal for C. W. Knight, xlv-xlvi.

'Pædumias transitans', development of, 296–301.

Paradoxidæ, ontogenies of, 266-79. Paradoxides spinosus, 319 & pl. xv.

Pararnioceras, sp. 640-41 fig. & pl. xxxviii.

PART, G. M., 536.

Paulton (Somerset), Lias in quarries near, 614-16.

Peniarth Anticline (Cader Idris), 576-77.

Penline Fault (N. Wales), geol. of country betw. Moel Arthur and, 185-86; do. betw. Y Fron-werth Fault and, 186-87.

Penmachno Beds, 173, 177-78.

Pennant Anticline (Cader Idris), 577. Penrhyn-gwyn lava, 552-53.

Pen-y-Gader (or Upper Basic) Group,

561-63 & pl. xxxv. Peripleuroceras rotundicosta gen. et

sp. nov., 646 & pl. xli. Phacoidal structure in Silurian of

Clwydian range, 190.

Phacopidæ, ontogenies of (& their

relation to Paradoxidæ), 279-85. Phacops-glaber Zone, Skelgill, petro-

graphy of, 132. Phyllis Hill Quarry (Somerset), 612

fig., 616. Phyric, term defined, 475.

PIDGEON, see DANIEL PIDGEON.

Pillow-lavas of Llanfachreth district, 508-13 fig. & pl. xxx.

Pitchstone of Hökulvikurgil, 327, 330–32 & pl. xx.

Pittsburgh (Pennsylvania), spherulitic siderite from, 682 w. anals.

Planktonic organisms in Silurian deposits, 120.

Planorbis Bed, 601 et seqq. Plas-newydd Beds, 173, 178.

Plateau Sands of Sierra Leone, 217–18 & pl. xiii.

PLATT, J. I., on the Pre-Cambrian Volcanic Rocks of the Malvern Inlier [title only], exxiv.

Platypleuroceras bituberculatum sp. nov., 650-51 & pl. xxxix.

— brevispina, 649 fig.

----- brevispinoides, 650 & pl. xl.

— cf. grumbrecti, 649. — cf. oblongum, 650 fig.

- aff. rotundum, 648, 649 fig.

Pleistocene non-marine mollusca of Avon Valley, 164-68; Pleistoc. & recent deposits of Sierra Leone, 217-18.

Plymog Fault (N. Wales), geol. of country betw. Bwlch-pen-Barras Fault and, 188; do. betw. New Mold Road and, 188-89.

POMPECKJ, J. F., elected For. Correspondent, exxix.

Portland Stone, fauna of basal shellbed of, exxviii; Echinoidea fr. P. S., exxviii-exxix.

Post-Tremadoc interval in Rhobell Fawr district, 469-70.

Powell Duffryn (S. Wales), spherulitic ironstone from, 677 w. anals.

PRESTWICH Medallists, list of, xxxii. PRINGLE, J., 533.

'Proparia' (& 'Opisthoparia'), 285-86.

Proparial Stage (in Trilobites) defined, 307-308.

Protaspid Period (in development of Trilobites) defined, 226.

'Pseudodiadema' (?) sp., exxviii.

Ptychoparidæ, &c., ontogenies of, 257-66.

Purbeck Beds, Echinoidea from, exxviii-exxix.

Quartz-diorite in Sierra Leone, 207. Quartz - keratophyre - tuff of Moel Offrwm, 504 fig.

Quartz - magnetite - schists of Sierra Leone, 199-200.

Quartz-porphyries of Hökulvikurgil, 328 et seqq.

Radiolaria assoc. w. spherulites in rhombohedral carbonates, 683-84 w. anals. & pl. xliii.

'Radley-Summertown Terrace' (Oxford district), elephant-remains from, 74 et seqq.

Radstock district (Somerset), Liassic rocks of, 595–666 figs. & pls. xxxviii–xli.

Radstockiceras complicatum, 642.

Ranegange Coalfield (India), spherulitic siderite from, 682.

Raricostatum Clay, 601 et seqq., 631.
RASTALL, R. H., Petrographical
Notes on the Stockdale Shales,
131-33.

RAW, F., on the Development of Leptoplastus salteri (Callaway) & of other Trilobites (Olenidæ, Ptychoparidæ, Conocoryphidæ, Paradoxidæ, Phacopidæ, & Mesonacidæ), 223–322 fig. & pls. xv-xviii, 323–24.

REYNOLDS, S. H., 221.

Rhiwisg Beds (or Whetstone Horizon), 173, 175-76.

Rhobell Fawr district (Merioneth), geology of, 463-538 figs. & pls. xxx-

Rhombohedral carbonates, spherulites w. radiolaria in, 683-84 w. anals. & pl. xliii.

Rhyolitic rocks in Rokell River Series, 211; of Moel Offrwm, 503-504; Rhyolitic (Mynydd-y-Gader) Group in Cader Idris district, 547.

RICHARDSON, W. A., part proceeds of Lyell Fund awarded to, xlviii.

Rifts & rift-valleys, lxxxiii. Rockhill Quarry (Somerset), 603 fig.,

607-608. Rokell River Series (Sierra Leone),

208-13. Rotation of the Earth, retardation of, exvii et seqq.

Saionia Scarp Series (Sierra Leone), 213-14 & pl. xii.

SANDFORD, K. S., on the Fossil Elephants of the Upper Thames Basin, 62-86 fig. & pls. iii-vi.

Sandstone Group (Upper Llandovery), 371-72.

Santo Domingo (Portugal), spherulites w. radiolaria from, 683-84 figs. w. anals. & pl. xliii.

. Sao, ontogeny of, compared w. that of Leptoplastus, 258-59.

SAYCE, R. U., xi.

Schaffer, F. X., 168-69; on the History of the Vienna Basin, i-ii. Scotland, see Southern Highlands.

SCOTT, D. A., obituary of, lxxiv. SEDGWICK Museum, 224.

SEWARD, A. C., obituary of R. Kidston, lxix-lxxi.

SHAKESPEAR, Dame ETHEL. 170.

Shineton Shales, trilobites of, 224 et seqq.

Sial (& sima), civ et seqq. Siderite, see Spherulitic.

Sierra Leone, geology of, 195-222 & pls. xii-xiv.

Silurian of central part of Clwydian range, 170-94 & pl. xi (map).

Sima (& sial), civ et seqq.

Sind, see Laki Series.

Sinemurian denudation in Radstock district, 627–29 figs.

Skelgill Beds, see Stockdale Shales.

Sмітн, В., 193.

Sмітн, H. G., 342-43, 415.

SMITH, R. A., obituary of A. W. Jamieson, lxxvi.

SMITH, W. CAMPBELL, 342; re-elected Secretary, xxv; receives Lyell Award for W. A. Richardson, xlviii; obituary of J. J. Stevenson, li-lii; obituaries of H. K. Jordan & R. F. Grantham, lxxi-lxxii; obituaries of B. E. Walker, D. A. Scott, & H. T. Burls, lxxiii-lxxv.

Soda-orthoclase in Hökulvikurgil rocks, 328-29 & pl. xx.

Sollas, W. J., obituary of E. A. Walford, lxxv-lxxvi.

Southern Highlands of Scotland, metamorphic zones in, 100-12 & pl. ix (map).

SPATH, L. F., 664.

Special General Meeting, ii.

SPENCER, E., on some Occurrences of Spherulitic Siderite & other Carbonates in Sediments, 667-703 figs. & pls. xlii-xliii, 705. Spherulitic siderite & other carbon-

Spherulitic siderite & other carbonates in sediments, 669-705 figs. & pls. xlii-xliii.

Spilites of Rhobell Fawr district, 504-fig., 511-13 w. chem. anals.; relat. of basalt to the same, 515-16.

Spilitic dolerites in Cader Idris range, 570.

Spiriferina Bed, 601 et seqq., 630.

STANLEY, E. R., obituary of, lxxviii-lxxix.

Stevenson, J. J., obituary of, li-lii. Stockdale Shales of Lake District, conditions of deposition & petrography of, 113-36 figs.

Stony Littleton Quarry (Somerset), 614.

STRAHAN, Sir AUBREY, obituary of A. Geikie, lii-lx.

STRAW, S. H., 405.

Strensham (Worcestershire), sect. of No. 5 Terrace at, 142.

Striatum Clay, 601 et segg., 632.

'Summertown-Radley Terrace' (Oxford district), from, 74 et seqq. elephant-remains

Sun-Bed (White Lias), 601 et seqq.

SWINNERTON, H. H., 322-23; on a New Catopterid Fish from the Keuper of Nottingham, 87-98 figs. & pls. vii-viii, 99.

Syenites of Sierra Leone, 207.

Talc-schists of Sierra Leone 197-98. Talyllyn Mudstones, 567-69; T. Fault, 582-83.

TEALL, Sir JETHRO J. H., obituary of, lxiii-lxv.

Tear-faults, lxxxix.

Tectonics of Cader Idris range, 574-83.

Teiran (or Passage-) Beds, 173, 176-

Tension, regions of, lxxx-cxxii.

Tetragramma ef. rougonense, exxviii. Thames Basin (Upper), fossil elephants of, 62-86 fig. & pls. iii-vi.

THOMAS, HERBERT H., 222, 534; Murchison Medal awarded to, xliii-

Тномая, W., 383.

THOMSON, J. A., part proceeds of Lyell Fund awarded to, xlvii-

THORODDSEN, TH., obituary of, lii. TILLEY, C. E., a Preliminary Survey of Metamorphic Zones in the Southern Highlands of Scotland, 100-10 & pl. ix (map), 112.

Timsbury (Somerset), Lias in quarries near, 617-20 fig., 621-22.

Tomlinson, (Miss) M. E., on River-Terraces of the Lower Valley of the Warwickshire Avon, 137-63 figs. & pl. x (map & sect.), 169.

Tooth measurement (Elephas), method of, 66-68 fig.

Tourmaline-schists of Sierra Leone, 200-201.

Tremadoc Beds in Rhobell Fawr district, 468-69.

Triarthrus becki, ontogeny of. 260-

Trilobites, ancestry, development, & classification of, 309-16; see also Leptoplastus.

Trochotiara thirriai, exxviii.

TRUEMAN, A. E., proceeds of Murchison Fund awarded to, xlvii; (& J. W. Tutcher), on the Liassic Rocks of the Radstock District (Somerset), 595-662 figs. & pls. xxxviii-xli, 665-66.

Trust-Funds & Special Funds, statement of, xxxviii-xl.

Tuffs of Rhobell Fawr, 476-79, 480. Turneri Clay, 601 et seqq., 630.

TUTCHER, J. W. (& A. E. Trueman), on the Liassic Rocks of the Radstock District (Somerset), 595-662 figs. & pls. xxxviii-xli.

Tutchericeras perfoliatum, 641.

Tyn-y-cornel Syncline (Cader Idris),

Tyning Colliery Quarry (Somerset), 600 fig., 607-608; T. Farm Quarry, 600 fig., 612.

Tyrau-mawr facies of Upper Basic Group, Cader Idris range, 563; T.m. Syncline, 577.

Uptonia aff. angusta, 647 fig.

distincta sp. nov., 647-48 & pl. xli.

- jamesoni, 646-47 fig. - aff. regnardi, 647. Uralite-porphyry defined, 485.

Valdani Limestone, 601 et segq., 632. Variolites of Rhobell Fawr district, 513-14 w. chem. anals.

VAUGHAN, J., 533.

VAUGHAN, T. W., elected For. Correspondent, cxxix.

Victoriceras iridescens sp. nov., 643 fig.

- victoris, 642.

Vienna Basin (Austria), history of,

VINCENT, H. C. G., 117.

Vobster (Somerset), Lias of, 613-14. Vogesite in Sierra Leone, 208.

Voluntary Publication Fund, list of donors to, xx.

WALFORD, E. A., obituary of, lxxvlxxvi.

WALKER, Sir Byron E., obituary of, lxxiii-lxxiv.

Wankie Coalfield (Rhodesia), spherulitic ironstone from, 677-78 & pl. xlii.

WARREN, S. H., 86.

Warwickshire Avon, river-terraces of lower valley, 137-69 figs. & pl. x (map & sect.).

WATSON, D. M. S., 61, 99. WATTS, W. W., 414, 461, 691.

Wealden Shales of Atherfield, Iguanodon atherfieldensis from, 1-61 figs. & pls. i-ii.

WEDD, C. B., 192-93.

Welford Pasture (Worcestershire), Pleistoc. non-marine mollusca

from, 168.

Wells, A. K., 134-35, 221, 342, 593;
 the Geology of the Rhobell Fawr District (Merioneth), 463-533 figs.
 pls. xxx-xxxii, 537-38.

Wellsway Quarry (Somerset), 600 fig.,

606-607.

Welton Hill Quarry (Somerset), 609.
Wenlock Series in Llandovery district, 373-76; in Garth district, 400; relat. of W.S. to Llandovery Series. 412-14.

Westfield Quarry (Somerset), 611, 612

fig.

WHITAKER, W., decease announced, vi; obituary of, lxi-lxii.

WILLIAMS, (Mrs.) M., 533.

WILLS, L. J., 163.

Winterfield Quarry (Somerset), 615. Wollaston Medallists & recipients of W. Award, lists of, xxviii; W.

of W. Award, lists of, xxviii; W. Medal awarded to G. W. Lamplugh, xlii—xliii; proceeds of W. Fund awarded to A. Brammall, xlvi.

Wolvercote (Oxon.), elephant-remains

from, 72 et seqq.

Woods, (Mrs.) E. G., 194; (& Miss M. C. Crosfield), on the Silurian Rocks of the Central Part of the Clwydian Range, 170-92 & pl. xi (map).

Woodthorpea wilsoni, gen. et sp. nov., 87-99 figs. & pls. vii-viii.

WOODWARD, Sir ARTHUR SMITH, 99; elected Vice-President, ii, xxv; obituary of C. W. Andrews, lxv-lxvi; reads R. W. Hooley's paper, 1.

WOODWAED, B. B. (& A. S. Kennard), on the Pleistocene Non-Marine Mollusca of the Avon Valley, 164— 68.

Woolacott, D., obituary of, lxxvilxxvii.

WOOLDRIDGE, S. W., 414-15, 533, 536-37, 664-65.

WYLEY, W. K., 224.

Xenocrysts of quartz, &c. in Hökulvikurgil rocks, 332-33 & pl. xx, 333-35.

Y-Fron-werth Beds, 174; Y-Fronwerth Fault, geol. of country betw. Penline Fault and, 186-87; do. betw. Moel Fammau Fault and, 187.

Ysgiog Anticline (Cader Idris), 577.

ZALESSKY, M. D., elected For. Correspondent, cxxix.

END OF VOL. LXXXI.



